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S U M M A R Y

The author, who was a captain of the Reserves in the Technical Department of the Aviation Division (Board of Airplane Experts) during the war, shows what means were taken for the creation of new airplane types and what tests were employed for trying out their flying properties, capacities and structural reliability. The principal representative types of each of the classes of airplanes are described and the characteristics of the important structural parts are discussed. Data regarding the number of airplanes at the front and the flying efficiency of the various classes of airplanes are given. (The matter is taken from a lecture delivered on April 17, 1918, at the meeting of the "Wissenschaftliche Gesellschaft für Luftfahrt," and supplemented at the termination of the war.)

Introduction.

The fact that the peace terms oblige us to give up military aviation entirely is a great compliment to German flyers and aircraft. Germany has good reason to be proud of the development of the vigorous technique which has been terminated thereby. The airplane industry is, for the greater part, under the necessity of turning to other work.

In reviewing the development of German military aircraft during the war we will only describe the main features and the principal types which resulted therefrom. The largest military airplanes, the R-airplanes, will not be dealt with here as their development has already been described in the 1919 journal, p.497 and following.

The Aviation Division systematically left the construction of airplanes to the airplane industry. By maintaining this attitude the Board of Airplane Experts which procured the airplanes,

*Special reprint from the "Zeitschrift des Vereines deutscher Ingenieure," 1920, p.493.

engines, and all the innumerable parts for the equipment and attendance of the airplanes, stimulated the various airplane companies to continuous competition and thus promoted progress. In England, on the contrary, the authorities at first designed the airplanes and had them built under their own supervision at the factories. For this reason the government was violently attacked in Parliament, the failure of the English airplanes towards the end of 1915 and beginning of 1916 being attributed to this fact ("The Aeroplane" December 27, 1916, and "Flight" December 28, 1916, and January 4, 1917.) The disadvantages of the German way, however, became apparent when the output had to be tremendously increased and the factories lacked trained men.

Thus the new types were not designed by the Board of Airplane Experts, but by one of the original German factories, of which there were about twenty. These new designs were as a rule made in consequence of requests from the front. Those at the front however did not restrict themselves to stimulating the construction of new types at home, but after the first encounters in the air, brought new types into existence themselves, by taking arms and bombs on their airplanes, for instance, and by improving their B-airplanes by installations, long before the arrival of the C-airplanes.

The A-airplanes were the old, unarmed, double-seater monoplanes, the "Tauben," a name which our adversaries at first gave to all German airplanes. The only German observation airplane, at the beginning of the war, was the B-airplane, a two-seated biplane. The C-airplane was the first to receive special equipment and afterwards three groups of them were built: for short range reconnoitering, a 200/220 HP vertical engine was used; for distant reconnoitering, a 260 HP vertical engine was used; and the Cl-airplane, that is, the lightened C-airplane, for convoying flights, in place of the original C-airplane with 150/160 HP vertical engine. The S-airplanes (Schlachtflugzeug-battleplane) with 260 HP vertical engines were designed for attacking targets on the ground, but they did not reach the front.

Armed one-seaters were used as pursuit airplanes: The E-airplanes were monoplanes which were withdrawn from service in the winter of 1916-1917, but which, towards the end of the war, again made their appearance with an improved construction. The D-airplanes were biplanes, and the Dr-airplanes (Dreidecker) were triplanes. They were usually equipped with two machine guns (M.G.), more rarely with three, and occasionally with wireless installation (F.T. - Funken Telegraphie) and a small fuel supply.

J-airplanes (Jagdflugzeuge-Pursuing or Battleplanes) like the C-airplanes were armored. Only very few N-airplanes (bombing airplanes with high carrying capacity for night flying) were built, as they were crowded out by the G-airplanes when the latter had to make their flights by day.

The airplane types mentioned so far had only one engine each, the G-airplanes (Grossflugzeug - large airplane) on the other hand, were all furnished with two. They had to carry bombs, and, most of the time, three men.

This explanation is not exhaustive because in actual practice the employment of the various types overlapped according to the need of the moment.

The variety of tasks at the front was so great that at first it was impossible to build a special class of airplane for each purpose. For a long time our aviators had to be content with a "general utility airplane": first the B-airplane, then the C-airplane, whereas a far-reaching adaptation to separate tasks would have made greater progress in construction possible. The problem confronting our adversaries was less difficult. The factories at their command were more extensive and their lines of supply and also their battle-fronts were shorter. They were therefore not obliged to limit the number of airplanes destined for special purposes. This start cleared the way for a similar development on our side in about the spring of 1915, because the armored airplanes, the bombers, and light one-seaters had to be outclassed.

Aviation construction was dependent upon the development of the engines, whereas in ship construction it is customary to adapt the engines to the purpose of the vessel. The airplane engine which had been developed separately was the decisive factor. The choice of the engine was determined by the efficiency, weight, reliability, size, number of revolutions, use of materials, and other properties of the engine, forming the basis of its reputation, such as smooth running and simplicity of repair. The engine industry placed at the disposal of airplane constructors about 15 types of vertical engines - the varieties within the types not being counted - and about eight types of rotary engines. The heavy but reliable and economical vertical engines out-number the lighter more sensitive and wasteful rotary engines. Each type of engine was used for a considerable number of airplane types. Table I shows the distribution of the airplane types and classes to the engine types. In the columns of the table are inserted the numbers of the airplane types which were built in series, (experiments being omitted). Tables 2 and 3 demonstrate better than words the extent of the industry which grew up in order to supply the needs of the troops.

TABLE 2.

Yearly airplane construction, grouped according to class.

Class	Construction year 1911	1912	1913	1914	1915	1916	1917	1918	Total
A	11	60	168	294	13	22	--	--	568
B	13	76	278	1054	1312	440	2993	25	6191
C	--	--	--	--	2674	4726	10337	7320	25057
D	--	--	--	--	1	2129	4945	5132	12207
Dr	--	--	--	--	--	--	338	1	339
E	--	--	--	--	347	300	--	381*)	1028
G	--	--	--	--	185	465	589	789	2028
I	--	--	--	--	--	--	450	463	913
N	--	--	--	--	--	100	94	10	204
S	--	--	--	--	--	--	--	2	2
Total	24	136	446	1348	4532	8182	19746	14123	48537

TABLE 3.

Yearly construction of airplane engines.

Time	Stationary engines	Rotary engines	Total
August to December 1914	748	100	848
January to December 1915	4544	493	5037
January to December 1916	6930	892	7822
January to December 1917	10364	836	11200
January to December 1918	13757	1785	15542
Total	36343	4106	40449

* These airplanes of type Fok EV were later renamed Fok D VIII although they were monoplanes.

It is to be noted that these engines correspond to a capacity of about 6,000,000 HP, whereas the Zschornewitz (Golpa) high power works have only a capacity of about 220,000 HP, and whereas the 5000 locomotives delivered during the war had a total capacity about equal to the capacity of the total number of airplane engines, the importance of aviation during the war, becomes apparent.

The Testing of New Airplanes.

After the engine had been selected, the specifications could be determined in detail, the requirements in this connection undergoing many changes. The general utility airplane, provided with four hours' fuel, had to carry two men and a load of 40 kg., a useful load therefore of 365 kg. The climbing capacity required was 800 m. in 15 min. After it was realized that the altitude necessary for war purposes was above 800 m., the requirements quickly rose to 1 km. in 10 min., 2 km. in 30 min., and the proof that 3 km. could be attained. For starting and landing 100 m. and 70 m. runs were prescribed.

With the later groups of types, the endurance, useful load, and climb were each changed. Stationary warfare made short flights possible and this diminished the amount of fuel necessary. The C-airplanes later relinquished the carrying of bombs; this resulted in airplanes with a good climbing capacity, and at the lower altitudes, especially good carrying power. The authorities at the front, mistaking the technical mission of the airplane, exploited this advantage by loading it to an unsuitable extent. In one case, for instance, a report from the front gave out that the flying capacity of one of these airplanes, built with a view to climbing qualities, was still efficient when loaded with 50 kg. of bombs. Unfortunately, the reduction of the structural reliability was not always considered on the occasion of such unreasonable overloading.

The airplane factories were obliged to observe the regulations prescribed by the Board of Airplane Experts regarding construction and delivery. These were changed several times, so that experience might be gathered, and for this reason also, the regulations became more and more elaborate. The Board of Airplane Experts not only influenced the airplane industry by laying down regulations, but urged by Major Wagenführ, - the commander of the Board of Airplane Experts - the airplane industry, the experimental stations, the experts and the military and naval bureaus decided to publish their scientific and technical work in a secret journal, called "Technical Reports of the Board of Airplane Experts."* This journal was to be published as needed and to be accessible to the ex-

* Now to be had at Carl Schmidt & Co., Berlin W., who are also going to publish a "Handbook on Aviation" (Handbuch der Flugzeugkunde), the scientific legacy of the Board of Airplane Experts. This work will comprise the results of all of the scientific work within the scope of the Board.

perts. In this way three volumes, rich in material, were produced in 1-1/2 years.

Before building a whole series of a type, a few trial airplanes were usually built, and these were tested with regard to flying properties, such as efficiency, structural reliability, capacity for resistance during operation, and adaptability with respect to reproduction. Unfortunately the tests were so extensive that not all of them were possible of execution. The flying properties, namely, the maneuverability and control of the plane at various altitudes and in various positions, was judged almost entirely by specially experienced pilots. The control surfaces were designed almost solely on the basis of experience gathered in earlier construction and were subsequently tested during flight. A method of calculating their reliability was discovered only during the last few months, so that judgment with regard to the flying properties depended, therefore, very largely upon personal opinion, and the many failures show that, up to the end, there was no agreement as to the properties which should be developed. It was not until later, that the Board of Airplane Experts worked at the development of a stability theory and its application in practical airplane construction. For longitudinal stability at least, a technically serviceable method was thereby found.

For the flying properties (climbing power and speed) a better evaluation was possible. Extensive calculations have cleared up the relations of climbing speed, engine output, propeller efficiency, viscosity of the air, weight of the airplane, properties of the wings, so that it was no longer necessary to form an estimate of the climb capacity based merely on previous experience. There remains the peace-time task of ascertaining each one of these values separately, which as yet is not quite possible in all cases.

According to the specifications first laid down for accepting an airplane, it had only to attain a prescribed altitude within a certain time. No investigations were made as to whether it could attain a considerably higher altitude or whether its ceiling had already been reached. As it is possible to draw any number of circles touching two points, but only one touching three points, as many ascending curves as desired may pass through two points upon a strip of barograph paper, but only one ascending curve through three points (Fig. 1). Later, therefore, not only the period of the ascent to a certain altitude was specified, but also the periods for several intermediate points, for instance from 3 to 4 km. and 4 to 5 km. From the autumn of 1916, as many airplanes as possible were required to be able to attain an altitude of over 5 km., and were, if possible, to retain good flying properties at that altitude. Therefore, with the ideal climb curve of the new airplane, the altitude limit which the airplane approaches asymtotically (assuming that the weight remains the same) was 6.5 km.

The climb curves received abbreviated designations. The class of airplanes built for climbing purposes, the climbing class of 5.0/45, attained 5 km. in 45 min. (class altitude), and their ceiling was increased 1.5 km., reaching 6.5 km. The airplanes of the climbing class of 15/20 attained 1.5 km. in 20 min. with a ceiling of 5 km. Fig. 2 shows a combination of ascending curves for various classes with a basic ascension period of 60 min. to the class altitude.

If the airplane becomes lighter as the fuel is consumed the altitude limit is, of course, increased. This increase was, however, only taken into account in individual cases when calculating the climbing capacity. Generally speaking, the full weight of the airplane on leaving the ground was decisive.

When measuring the climb, the season of the year exercises a strong influence on the results and was taken into account, for awhile, as follows: The average air strata, as calculated according to meteorological tables for each 1/3 of a month, was assumed. This was, however, not sufficient as the daily condition of the weather deviated too much from these averages. On the other hand, with the great number of airplanes that had to be accepted, practical considerations prevented taking the daily variations of the weather into account. In the end, when testing a type, it was considered sufficient to measure the periods of ascension very accurately with the aid of air pressure and temperature recorders, and use the ascension times in the acceptance tests only for the purpose of a general comparison.

Speed was not measured regularly. To accomplish the latter steady, horizontal flights are a requisite, and even trained pilots cannot always accomplish this accurately. At lower altitudes, where it is easier to hold the airplane at a certain level by reason of the direct comparison with the ground, the number of revolutions of the engine is too high and the pilot is obliged either to throttle the engine or to use the elevators, either of which spoils the results of the experiment. Altimeters which facilitate adherence to a certain altitude were not built to use for speed measurements only. In the future they will gain in importance for surveying by taking photographs from an airplane. For measuring speed, either static measuring apparatus or wind gauges were used, in the airplane. The indications of the former were, however, dependent on the altitude of the airplane and the indications of the latter were based on the rotation of an air propeller or cup-vane. Both kinds are dependent upon their position in the airplane. In consequence of the uncertainty of the speed measurements, the most confusing reports were in circulation about speeds that had been attained or were attainable.

The Board of Airplane Experts, it is true, specified minimum speeds, but was obliged to relinquish systematic verification of the tests, as they lacked suitable measuring processes to govern the acceptance of the airplanes. The speed was judged merely by comparison with the speed of other airplanes that had been tried out at the front. At the same time the new airplane was observed with regard to its climbing properties, horizontal flight and glide as compared with the airplane already thoroughly tested. Experiments regarding speed measurements with the aid of theodolites were made at Doberitz in 1916, later again at Adlershof and finally near Lake Muritz in Mecklenburg. It is apparent from the results that, generally speaking, the estimate of the speed of the airplanes was too high.

The following speeds are probably about correct:

TABLE 4.

Speeds attained by airplanes.

Class	Horizontal Sped without altitude engines km/hr.	Horizontal Sped with altitude engines km/hr.	Remarks
Battleplane	135 to 140	165 to 170	altitude about 4 km.
C-airplane (strong	135 to 140	160 to 165	
(weak	125 to 130	140 to 145	
Cl-airplane	--	160 to 165	
G-airplane	115 to 120	135 to 140	

With the outlining of the efficiency and performance specifications, the acceptance tests for an airplane type were exhausted. Before commissioning a type, tests were always made for the reliability of the structural parts. The practice, which had been instituted in the Aviation Division since the accidents of the autumn of 1913, of testing the wings by loading them with sand in which the effects of the air forces was imitated by piling up the sand unequally, was elaborated and extended. In accordance with the greater strength required for battleplanes, several very important flying attitudes were tested under several conditions in the endeavor to be certain that the airplane would be strong enough when pulling out of a dive, when diving, gliding, or when flying upside down. The tests, furthermore, covered all the important structural parts, such as wings, stabilizing planes, steering gear, fuselage, and landing gear. Calculations of experiments with models, measurements made during flight, and calculations based on actual experience in aerial navigation (supplementary work in this connection being constantly in progress) served as a basis for these tests. By the end of 1918, the testing station at Adlershof had worked on about 200 airplanes and completed about 2000 separate tests.

As these strength tests were very costly, a means was sought to reduce the expense. From the beginning of 1916, therefore, mathematical strength analyses were required from the airplane constructors as a basis for the tests of the new airplane types. As this was not sufficient without definite specifications, the Board of Airplane Experts was itself obliged to work out the lines along which the static calculations were to be made. The work of Müller-Breslau, Reissner, Baumann and Mann was used in this connection. In furtherance of this work, Müller-Breslau published in the "Technical Reports" (Technische Berichte) an account of a detailed investigation conducted for the purpose of calculating the strength of airplane wing beams. Unfortunately the strength calculations for airplanes are so complicated that the results (which in addition are often open to question on account of the uncertain property of raw material), do not repay the work.

For the present it will therefore be necessary to depend on actual tests in order to obtain a reliable estimate of the strength of an experimental construction. It is furthermore not yet possible to exclude these tests because the metal fittings and other important structural parts cannot be tested on the strength testing machine to an extent corresponding to actual use. In addition to these tests the weight statistics which the Board of Airplane Experts steadily demanded, and which were verified and supplemented during the testing of the airplanes for strength, were of great value in forming an estimate of the manner of construction.

A number of the breakages in the structural parts during operation were the result of vibrations which were caused partly by resonance with the revolutions of the engine and partly by the rhythmic eddy effect along the sides of the wings. The means for avoiding these vibrations is known.

The Board of Airplane Experts, in conjunction with the model Experimental Establishment at Göttingen, continued to make investigations in the extensive field of aerodynamics. Although industry had shown a lively interest in the work at Göttingen and Adlershof, the results of the measuring of the models were not adopted to the extent they deserved, because the Board of Airplane Experts required no proof of the aerodynamic properties of the airplanes, and because the demand for new airplanes always exceeded the supply. It is true that most of the experimental departments of the airplane factories were provided with ample means but these were seldom used for the systematic investigation of the cause or effect of some phenomenon, but were, for the most part, exhausted in the simple empiric search for the best execution possible. Special measuring apparatus for experimental flights was therefore almost entirely lacking. Thus the Göttingen Model Experimental Establishment has not yet succeeded in having its wing rib measurements verified during flight. Much remains therefore to be done in connection with the investigation of the airplane in flight. Since only the technically perfect airplane can be successful, the airplane industry will be obliged to make up this work. The authorities who pass on the admission of airplanes for aerial traffic, but who do not, like the Board of Airplane Experts, take them over for their own purposes, will in the future be obliged to require proof of the flying ability of the airplanes and calculations for the flying properties as well as strength.

TABLE 5.

Airplane Class	Engine outfit: Rotary: Stationary (h.p.)	No. of Airplane	Useful Load. Occupant No.	Occupant kg.	Armament and Ammunition: Description	Armament and Ammunition: kg.	Bombing: Description	Bombing: kg.	Wireless and photographic outfits: Description	Wireless and photographic outfits: kg.	Fuel: Sufficient for (hr.)	Fuel: With a load of (kg.)	Unused load (kg.)	Total (kg.)	How employed up to the termination of the war.
A	100 St.	1	2	180	none	--	none	--	none	--	4	145	40	365	Formerly reconnaissance; latterly withdrawn from the service.
B	100/ 120 St.	2	2	180	none	--	none	--	none	--	4	145	40	365	Formerly reconnaissance; latterly equipped with double steering apparatus for training school at home.
	150/ 160 St.										4-1/2	172	40	492	Used at home for training.
C	200/ 220 St.	2	2	180	1 fixed M.G. 1 movable M.G. with ammunition	100	Formerly provided with installation for 50 kg.	--	Provided with wireless & photographic outfit		3-1/3	196	40	516	Short range reconnaissance at the front.
	260 St.									20	3-3/4	240	40	580	Long distance reconnaissance at the front.

TABLE 5 (Cont'd)

Airplane Class	Engine Outfit. Rotary. Stationary. h.p.	No. of Airplane	Occupant No.	Occupant kg.	Armament and Ammunition: Description	Armament and Ammunition: kg.	Bombing: Description	Bombing: kg.	Wireless and photographic outfits.: Description	Wireless and photographic outfits.: kg.	Fuel: Sufficient for hr.	Fuel: With a load of kg.	Unused load kg.	Total kg.	How employed up to the termination of the war.
Cl	160/180 St.	2	2	165	1 fixed M.G. 1 movable with ammunition	61.5	none	--	Provided with wireless outfit.	21	3	109.5	3	360	Convoying airplanes at the front.
	100/120 St.			100	1 fixed M.G. with ammunition.	50					2	70	--	220	Training planes at home.
D	160 Rot.	2	1	100	2 fixed M. G. with ammunition.	70	none	--	none	--	1-1/2	63	--	233	Withdrawn from the service.
				80		47.6					1-1/2	51	16.4	195	
	160 St.			100		70					2	65	--	235	Pursuit planes at the front.
	180 St.			80		47.6					1-1/2	43.3	9.1	180	
Dr	110 Rot.	3		80		47.6					1-1.2	41	11.4	180	

TABLE 5 (Cont'd)

Airplane Class	Engine Outfit (Rotary, Stationary) h.p.	No. of Airplane	Occupant No.	Occupant kg.	Useful Load. Armament and Ammunition: Description	Armament and Ammunition: kg.	Bombing: Description	Bombing: kg.	Wireless and photographic: Description	Wireless and photographic: kg.	Fuel: Sufficient for hr.	Fuel: With a load of kg.	Unused load kg.	Total kg.	How employed up to the termination of the war.
E	80/120 Rot.	1	1	90	1 fixed M.G. with ammunition	50	none	--	none	--	2	70	--	210	Formerly pursuit airplanes; latterly withdrawn from the service and only represented at the front by one type.
	160 Rot				2 fixed M.G. with ammunition	70					1-1/2	63	--	223	
G	2 - 150 St.	2	2	180	2 movable M.G. with ammunition	100	Various arrangements	200	none	--	4	435	--	935	Those still in existence are training airplanes at the front.
	2 - 220 St.			270							3-2/3	440	--	1010	
	2 - 260 St.		3	245	4 movable M.G. with ammunition	130		300		26.5	3-1/2	508	25.5	1235	Bombing airplanes.

TABLE 5 (Cont'd.)

Airplane Class	Engine Outfit Rotary Stationary h.p.	No. of Airplane	Useful Load. Occupant No.	Occupant kg.	Armament and Ammunition Description	Armament and Ammunition kg.	Bombing Description	Bombing kg.	Wireless and photographic Description	Wireless and photographic kg.	Fuel Sufficient for hr.	Fuel With a load of kg.	Unused load kg.	Total kg.	How employed up to the termination of the war.
J	200 St.	2	2	165	2 movable M.G. with ammunition	76.5	none	--	Provided with wireless and photographic outfit	21	3	135	12.5	410	Infantry planes.
N	260 St.	2 or 3	2	170	1 movable M.G. with ammunition	35	Various arrangements	500	none	--	4	290	5	1000	Under construction; bombing planes for night work.

After these tests the airplanes were sent to the front and the judgement passed upon them was awaited and utilized. The quick growth of the Aviation Division, it is true, increased the difficulty of this work because the number of aviators capable of good technical judgment was proportionately smaller. It was impossible to organize, within the Aviation Division, specialized Aviator Sections commissioned with the task of trying the airplane types because the replacements for these specialized sections would have been difficult to find.

It is true that towards the end of 1914 and 1915 there was such a section - the well known "Brieftauben-Abteilung Ostende" (Carrier Pigeon Section). Its technical reports were especially esteemed for their clarity. Faults in airplanes delivered were altered as soon as possible in the later series. One of the essentials in this connection was to avoid delay in replacements.

The knowledge gained by comparisons with enemy airplanes was of great value as this afforded a means of finding out how to outstrip the adversary, so the numerous captured airplanes were useful for this purpose. Thus the Nieuport airplane of 1916 showed flying properties that were technically advantageous and which were imitated in many types. The difference of the armament, bombs, wireless apparatus and other parts of the equipment, but especially the engines, made it impossible to take over tried out types of enemy airplanes. In order to imitate the style of construction of the model types of enemy aircraft we would have had to make radical changes in our workshops. A faithful reproduction of the enemy airplanes was furthermore impossible on account of the raw material situation in Germany, and finally, it would have violated the consciences of the greater number of our engineers to take over the styles of construction of the enemy which on the basis of their experience they considered unreliable. In spite of this we learned much from our enemies, who evidently had good factories and investigating plants at their command. But we were not their pupils, and we did not copy their celebrated large Handley Page airplane in the construction of our large aircraft because the G-airplanes of the Gothaer Waggonfabrik were ready for flights to England as early as the winter of 1916-1917, at which time the new Handley Page airplane landed behind our lines by mistake and was captured.

With the great number of types which came into existence during the course of the war, much work was caused by the obtaining of new airplanes and the many spare parts, that it became necessary in 1917 to standardize the parts as much as was possible without prejudice to the types. Standard patterns were worked out by the War Association of the airplane industry and were then included in the requirements given out by the Board of Airplane Experts. This constituted the beginning of a standardization of aircraft in general which was bound to come to pass in the course of time.

CLASSES.

Table 5 comprises all the classes of airplanes and indicates the distinguishing features of their special purposes. Since the use to which airplanes at the front were put, varied considerably, this compilation represents a cross-section of uses at one time.

Fig. 3 shows at what times and in what numbers the different airplanes occurred at the front and how the newer types displaced the older ones. The A-airplanes disappeared first. A few were still used here and there behind the front lines in the second year of the war on account of individual preferences. The number of B-airplanes increased quickly and was greatest toward the end of the first year of war and at the beginning of the second. Until the introduction of the Cl-airplanes in the winter of 1917-1918 the C-airplanes show no decrease in numbers and then only a slight decrease, which is to be ascribed to the diminished aeronautic activity and the preparations for the spring of 1918, but in the third year of the war, the B-airplanes quickly disappeared. With the end of the first year of the war, the first pursuit airplanes - the E-airplanes - made their appearance at the front. Their numbers increased until the spring of 1916, and were then replaced by the D-airplanes. The number of the latter and also the Dr-airplanes was constantly increased from the beginning of the fourth year as aerial warfare continued to gain in importance. The first G-airplanes were sent to the front in the summer of 1915. It was not until the third and fourth years of the war that the latter increased in numbers, together with the growing frequency of the bombing attacks behind the lines and especially in England. The armored battleplane - the J-airplane, was first tried out and proven successful in the autumn of 1917. Fig. 3 shows plainly the great numbers of airplanes sent to the front just before the armistice, after a painful interruption of the aircraft supply had occurred in June, 1918.

The A and B-airplanes had both been used for the same purposes and were unarmed. The Rumpf-biplane of the Luftverkehrs-Gesellschaft Lvg Bl, (Fig. 4) was used as a model. In the B-airplanes the observer had the seat most advantageous for him, directly behind the engine and in front of the pilot. He could also lean out and take photographs. The pilot was able to overlook the rear of his airplane, a much vaunted advantage which facilitates steering.

The 150/160 h.p. C-airplane was a development of the armed B-airplane. The observer sits behind, since if in front, the field of fire of the machine gun would be obstructed by the propeller and the wings, whereas at the back it is obstructed only by the fuselage and tail surfaces. With very few exceptions all the C-airplanes have this seating arrangement; the AEG Cl (Fig. 5), of the AEG Airplane Construction Division, Hennigsdorf, may serve as an example. Fuselage and wing beams consisted of steel tubing as in other construction of this plant. Its wings could be folded back when passing through the streets (Fig. 6) a feature which was abandoned by us as superfluous, but which was used again later in the Handley Page airplane in order to facilitate putting this large airplane under cover. The accessibility of the engine (Fig. 7), beneath the hinged cup-like cowl, may even at the present time be used as a model, but in this construction, care must be taken to have a fastening that is reliable during flight.

The increasing demands resulted in providing the C-airplanes also with the machine gun which shoots through the propeller and which had proven satisfactory on the E-airplanes.

Efforts were now concentrated on providing a clear field of vision for both occupants. A good solution of this problem is shown in the Rol C II airplane, known as the "Whale" (Walfisch) of the "Luftfahrzeug Gesellschaft" (Fig. 8), which shows the first well executed streamline fuselage. In former experiments along this line, the tail surfaces had not been designed with sufficient effectiveness for a rounded fuselage, with the result that it was thought that rounded fuselages resulted in difficult control. The skin of the fuselage was constructed of laminated wood on templates with the strips crosswise, a process which later took its place beside the process of laminated wooden panels introduced by Albatros a few years previously and which became common property.

Of the C-airplane varieties the AGO.Cl of the AGO Airplane factory may be mentioned, in which the engine was behind the occupants, and, in place of the customary single fuselage, there were two lateral fuselages. The Automobile and Aviatik A. Co. furnished their C-airplane with sliding rails for the machine gun on both sides of the fuselage, so that the observer might be able to remain in front.

In the summer of 1916 the 200/220 h.p. C-airplanes were brought out. The DFW C V of the Deutsche Flugzeugwerke was very popular and it was possible to have it reproduced at other factories.

The 220 h.p. D IV engine of the Daimler Motor Company, was the only stationary engine with an increased efficiency due to a spur gear system for diminishing the number of revolutions of the propeller. The Alb C V (Fig. 9) of the Albatros Works which was furnished with this device displayed remarkable efficiency. The smoothness of the D IV engines was, however, not satisfactory but all efforts to produce another kind of stationary engine with transmission gearing that was serviceable for the front were unsuccessful. In spite of the fact that engines with transmission gearing to propellers of large diameter possess the disadvantages of additional engine weight and frequently high-legged undercarriages, they are, by reason of their greater efficiency, superior to the high speed propeller.

A glance at the pilot cockpit of a more recent C-airplane, LVG C V (Fig. 10), shows the control stick in the middle with the trigger for the fixed machine gun on the upper right; to the left are the switches for operating the engines; below, on the left, is the wireless dynamo with V belt drive; and to the right, the compass. The box in the front contains the cartridge belt, while the revolution counter is fastened to the steel tube which supports the machine gun.

With the C-airplanes, the adequate provision for the equipment (which was however just as important as the flying properties and the efficiency of the airplane) was, at the time of designing, often neglected in favor of the smoothness of the fuselage. This frequently delayed the commissioning of the airplanes for weeks.

Of the airplanes constructed with 260 h.p. engines, only those types developed from the Rumpler C IV of the Rumpler factories and which at the last were furnished with high altitude engines, held their own. The last of this series was the very promising Rumpler C X (Fig. 11).

With the Cl-airplanes, a cross between the C and D-airplanes, special stress was laid upon effective armament and climbing power, and the following types should be mentioned, in addition to the types of the Halberstadter Airplane Works, the Hannover C IV (Fig. 12) of the Hannover Waggonfabrik, and the metal airplane Junker C II of the Junkers-Fokker Works (Fig. 13), the latter being characterized by lack of wing bracing and less weight. The fundamental investigations of Duralumin airplane construction by the Junkers Research Station are proving useful for present day passenger airplane construction. Similar investigations were conducted at the Zeppelin Works in Lindau, where Dornier himself used metal rods for airplane construction. If the use of lightweight metal is more wide-spread in Germany than elsewhere, the credit is due to both of these Research Stations.

Fig. 14 shows the alternating of the C-airplanes at the front. The chart shows the large numbers of 150/160 h.p. airplanes in the second and third years of the war; the most important types were: Albatros, LVG, Aviatik, Rumpler, Roland, and

AGO airplanes. The Rumpler CI of the Rumpler Werke and its reproductions by other companies, held its own the longest at the front, as also did the Albatros CV with 220 h.p. geared motor. The 260 h.p. airplanes appear in the middle of the third year, these being the most successful constructions of the Rumpler Works.

The pursuit airplane was only developed into a serviceable weapon when the machine gun was synchronized by means of the engine.* Figs. 15 and 16 show the type which became known through Boelcke, Fokker E III of the Fokker-Flugzeugwerke. A cam has been connected to the 160 h.p. 14-cylinder rotary engine of the Ober-Ursel Motor Factory, the cam operating the trigger rods of the three machine guns. The cams lock the guns as soon as the blades of the propeller are in front of their muzzles. The monoplanes were later abandoned on account of their obstructed field of vision and insufficient flying properties, in favor of the biplanes with stationary engines. The upper wing was placed so that its chord if lengthened would be level with the eyes of the pilot (see Fig. 17 - Albatros DV of the Albatros Co.). In this airplane the upward and forward view was improved. Only the lower wing still presented an obstruction. The latter was, however, not so wide as the upper wing and set with slight backward stagger.

By bending his head slightly the pilot was able to sight both right and left machine guns and in spite of being strapped in was able to overcome any jamming of the machine guns that might occur.

In the Pfalz D IIIa (Fig. 18), is to be seen the clear direct view upon which Rittmeister von Richthofen laid such stress. The Fokker airplane, the Fokker D VII (Fig. 19), with the Bmw IIIa engine of the Bavarian Motor Works was the most valuable type of pursuit airplane at the time the war ended and for this reason had to be surrendered.

The triplane (Fokker Dr I) of the Fokker Airplane Works (Fig. 20) with a 110 h.p. Le Rhone engine was also valued as a pursuit airplane on account of its good flying properties. The wings had an uninterrupted span with single wing beams and were internally braced, but were connected by struts in order to reduce vibration. The triplane was given due consideration theoretically and practically, as it was hoped that it would be structurally lighter with an equal or superior flying efficiency. Nevertheless, the biplane was retained as it is inferior to the triplane only in the ability to turn quickly and easily. With heavy airplanes the idea of diminishing the span by adding a third pair of wings was

* The services of Fokker in this development are well known. The patent for the synchronization gear belongs to the L.V.G. Company, and that for the fixed machine gun to August Euler.

very tempting, but comparative calculations have shown that triplanes are only economical when they are made with the same span as biplanes.

Fig. 21 shows the number of pursuit airplanes at the front. The G-airplanes which at the last had two 260 h.p. engines, were especially constructed as bombing airplanes. A well known development is the Go GIV (Fig. 22), of the Gothaer Waggonfabrik. The armament served less for attack than for defense, and was chiefly towards the rear. In order to limit the range left uncovered by the fire of the machine gun, the fuselage was slit lengthwise, and in this way a gun tunnel (Fig. 23) was made through which the adversary, when hidden under the tail surfaces, might be fired at from the upper machine gun stand. The influence of this gun tunnel on the speed of the airplane, was moderate. The bombs were suspended in rows under the fuselage, and it is true that their suspension increased the air resistance. The bow of the fuselage was executed in a free curve and afforded the observer a clear view. To the left, behind him sat the pilot with his instruments. The observer could retreat to an emergency seat to the right of the pilot in case of a dangerous landing. Behind this sat the machine gunner. The seats of the observer, machine gunner and pilot were connected by a passage way.

The Gothaer Waggonfabrik and the Flugzeugbau Friedrichshafen built their G-airplanes with pusher propellers. In this position the propellers were exposed to great danger by reason of stones flung up by the landing gear or engine parts that might become loose. For their AEG G IV (Fig. 24) the AEG Company therefore used tractor propellers, and the fuselage and wings, as in all the AEG airplanes, were constructed with steel tubing. In the switch installation in front of the pilot, as shown in Fig. 25, all the switches are connected in a model way so that only very little manipulation is necessary for operation.

The Fdh G III of the Flugzeugbau Friedrichshafen, which had been tried out and which had held its own successfully, was similar to the Go G IV with regard to external measurements, and also possessed the advantages of being well arranged for taking apart for transportation by railroad, as the front and rear sections of the fuselage could be separated from the central main section. The shock absorbing gear, as well as the main undercarriage (Fig. 26) were examples of novel construction.

In the G-airplanes the fuel was placed either laterally under the engines or in the main body. Neither place offers sufficient security against fire. An improvement in this connection involves much important work. Fig. 27 shows the number of G-airplanes at the front.

The Junker JI of Junkers Werke carried about 400 kg. of 5 mm. steel armor and was protected against gun fire also by the internal bracing of the wings. The engine, fuel tanks and occupants were protected by the armor (Fig. 28).

The N (night) airplanes were built with great carrying capacity but with little climb and were slow. Therefore, they were not in favor at the front but will be able to serve as a construction example of transportation airplanes.

STRUCTURAL PARTS.

Almost all the structural parts of the airplane depart from the rules of other technique, in consequence of the building material being necessarily chosen with reference to elasticity, strength, weight, workability, obtainability and resistance to the weather and with reference to the special operational requirements. The tendencies of automobile, bicycle and yacht construction can still be traced. Building materials, such as wood of all varieties, linen, canvass, cellon, casein glue, welding and cold-rolled sheet steel, medium and high tensile steels, aluminum and its alloys, etc., are employed in places where the technique of construction is important, and where the properties of these materials must be made to harmonize with one another. As the life of the airplanes during the war was brief, lasting only a few months, it was for the most part, not necessary to take account of aging. With the coming of transportation airplanes, this will, however, have to be most carefully observed.

The ribs (Fig. 29) which, after the doped linen, are the most important carrying feature of a wing, are manifold in shape. The form of the ribs gives to the wing its prescribed aerodynamic cross-section. Solid ribs, when narrow, are as shown by experiments, equal to the hollowed out ones in weight, but are cheaper to make. The fastening of the ribs to the wing beams requires great care and is difficult, as the wing beams must be as high as possible, and the thickness of the rib capping strip therefore must necessarily be small. The construction of the wing beams also has been extensively developed. They consist of several parts glued together as shown in Fig. 30. Great experience is necessary for the distribution of surfaces glued lengthwise and crosswise, and for arranging the layers of the laminated wood in such a way that the cross-sections of the same are not only strong but weatherproof. The metal wing fittings (Fig. 31), must weigh as little as possible, must be joined to the wings as smoothly as possible and must not necessitate eccentric bracing connections. At the body, the connections must be easy to loosen (compare No.4), a device of the Rumpler C-airplanes. The arrangement for transposition, (compare No. 1) (Alb CIII), is also advantageous for learning to fly. Mountings for the steel tube wing beams were also designed by the AEG (compare No. 2). The characteristic wing suspension of the Ru D I of the Rumpler Werke (Fig. 32) unites the main carrying wires of the lower wing below the frame of the fuselage and in this way lessens the weight of the mounted parts to a minimum.

The lack of raw rubber made it necessary to do without the light rubber shock absorbers of the undercarriages and to use instead spiral springs laid one inside the other in the same way as the wound rubber cords. Realizing that springs made of thin wire are lighter, the AEG designed a very serviceable spring (Fig. 33). The top and bottom of the springs, which may easily be changed, are hooked into staples which are connected with the axle and with the undercarriage.

COMPARISON OF THE PERFORMANCES.

The old 100 h.p. B-airplanes require 46 min. to attain an altitude of 3 km.; the 150/160 h.p. C-airplanes require only about 26 min. The fact must be accentuated that the latest 260 h.p. C-airplanes fitted with high altitude engines, attain an altitude of 6 km. in about 42 min., while an up-to-date pursuit airplane climbs 7 km. in about 26 min. It weighs about 820 kg., and the average climbing speed is:

$$w = \frac{7000}{26.60} = 4.5 \text{ meters per sec.}$$

The average lifting capacity is accordingly

$$N = \frac{820.4.5}{75} = 49 \text{ h.p.}$$

with an average engine output of 150 h.p. Therefore, the energy expended on the lift is about 1/3, a high figure when remembering that the propeller alone has an efficiency of 70%, therefore that an allowance of about 56 h.p. must be made for the carrying of the airplane itself.

The continuous lines shown in illustrations 34 to 37 give the measured altitudes, and the broken lines give the extrapolated altitudes. For the airplanes with high altitude engines, the curves were also extrapolated downwards, as the high altitude engines do not attain their maximum output at the ground. The airplanes with high altitude engines would, according to this, save a few more minutes on the climb with the throttles wide open.

The efficiency load $\left(\frac{\text{Total weight of airplane}}{\text{theoretical engine output at the ground}}\right)$ of the military airplanes is far too low for profitable aerial traffic. As quick climbing ability and high ceilings are of little importance for transportation airplanes we may look for an increase in the efficiency load up to the limit practicable for safe starting and landing.

Fig. 38 shows the altitude limits of the German airplanes in 1918. We draw attention to the three altitudes connected with the various tasks. The pursuit airplanes circled at the highest altitude in order to protect the working airplanes. Below the latter were the infantry airplanes aiding the battle on the ground.

(Translated by the Office of Naval Intelligence, Navy Department, Washington, D. C.)

A1000-43

W. HOFF _ THE DEVELOPMENT OF GERMAN AVIATION DURING THE WAR

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE

DESIGNED
DRAWN Faut 9/30/920
CHECKED W. M.
APPROVED W.K 10/11/20

B 36

TABLE 1

Number of "original" and "licenced" airplane types constructed for different engine types in various classes of airplanes

Class of engine		As II	As III	Bus IV	Bow	Bz II	Bz III	Bzm bo	Bz IV	DZ	D II	D III	D IV	D IVa	Man am	Mb IVa	C III Nag	Uo	U I	W III	Coe III	Ur II	Ur III	Sh I	Sh III		
Type of engine with single type improvements							IIIa, IIIav	IIIbm, IIIbr	IVü, IVs, IVsü			IIIa, IIIü, IIIaü, IIIav, IIIb					IIIa, IIIb										
Nominal H.P.		120	180	250	185	110	150 bis 185	195	200	100	120	160 bis 180	220	260	185	260	185	70	100	140	160	110	180	100	160		
Class of airplane																											
"Original" types	A		1							8								5	1							16	16
	B	18°				18°				18°/1	18°/1							2	2							24	78
	C		2				19x/2		9			19x/5	2	5		6	1									51	70
	CL		2									6														8	8
	D	3	2+		2△/1		1	1		1	3	2+ 2° 15			2△				4	1	2▽	3	2▽	1	9 2▽	43	53
	Dr					1																			1	2	2
	E									1								3	3	2		1	1	1		12	12
	G						4		3			1	3	13/1□		1□										25	26
	GL													1□		1□										1	2
	J								6																	6	6
	N						1		1																	3	3
	S																										
	Total																									190	275
"Licenced" types	B	18°				18°				18°/1	18°															19	73
	C		4 4+	2			23x		11			23x 4+	1	9			1									55	82
	CL		2									2														4	4
	D		1+		2△						2	2△ 1+5			2△											10	15
	G								1					6		1										8	8
	GL													2		2										4	4
	Total																									100	186

° Types are equally adapted for As II, Bz II, O I, O II
× " " " " Bz III, O III
+ " " " " As III, O III
△ " " " " O III Br. v IIIa, Man a III
▽ " " " " Goe III, Ur III, Sh III
□ " " " " Mb IVa, D IVa

Total number: 190 "original" type and 100 "licenced" types, total, 290 types. If a special calculation be made of such types as are adapted for various engines, their number would be as follows: 275 "original" types and 180 "licenced" types, total, 461 types.

Notes - "Original" airplanes are those manufactured directly by the firm holding the patents _ "Licenced" airplanes are those constructed by contractors according to existing patents.

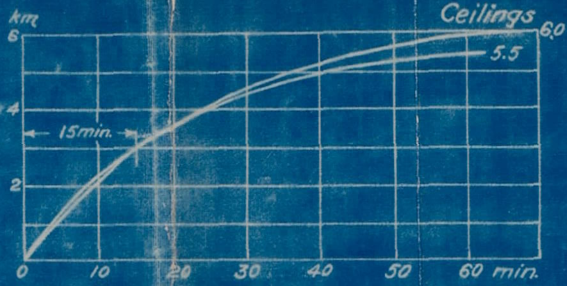
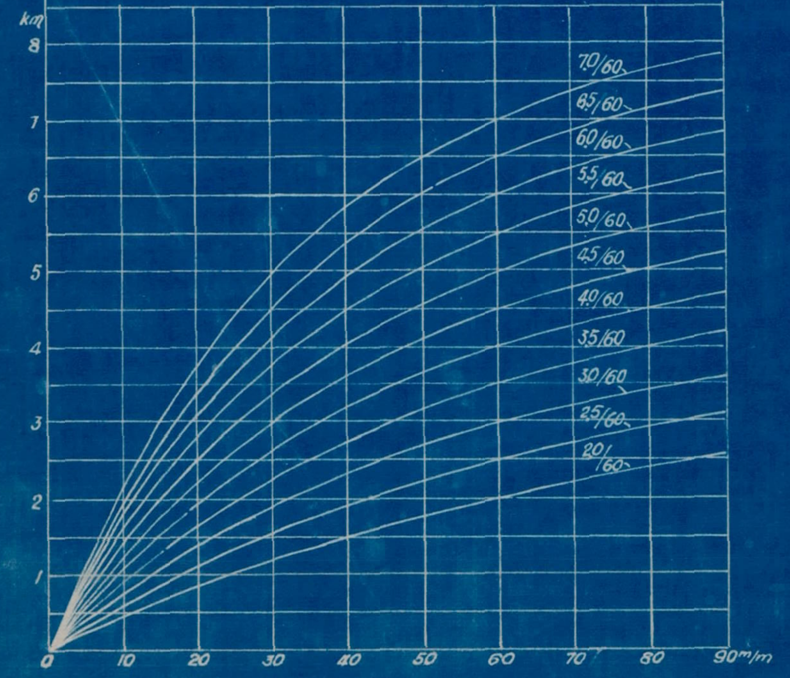


FIG. 1 Comparison of two ascension curves with the same period of ascension (namely, 15 min. for an altitude of 3 km), but having different ceilings.

FIG. 2 CLASS OF CLIMB

4.0/60 signifies that an altitude of 4 kilometers has been reached in 60 minutes. The ceiling is at 5.5 km.



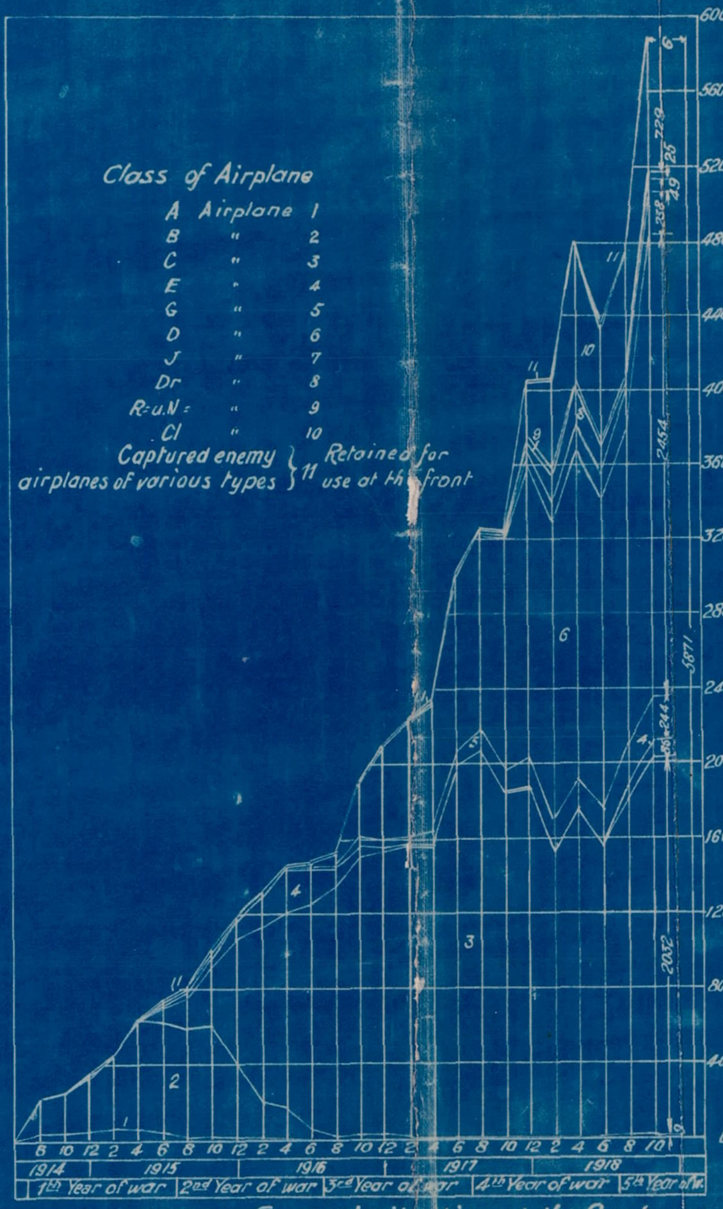


FIG. 3 _ General situation at the front

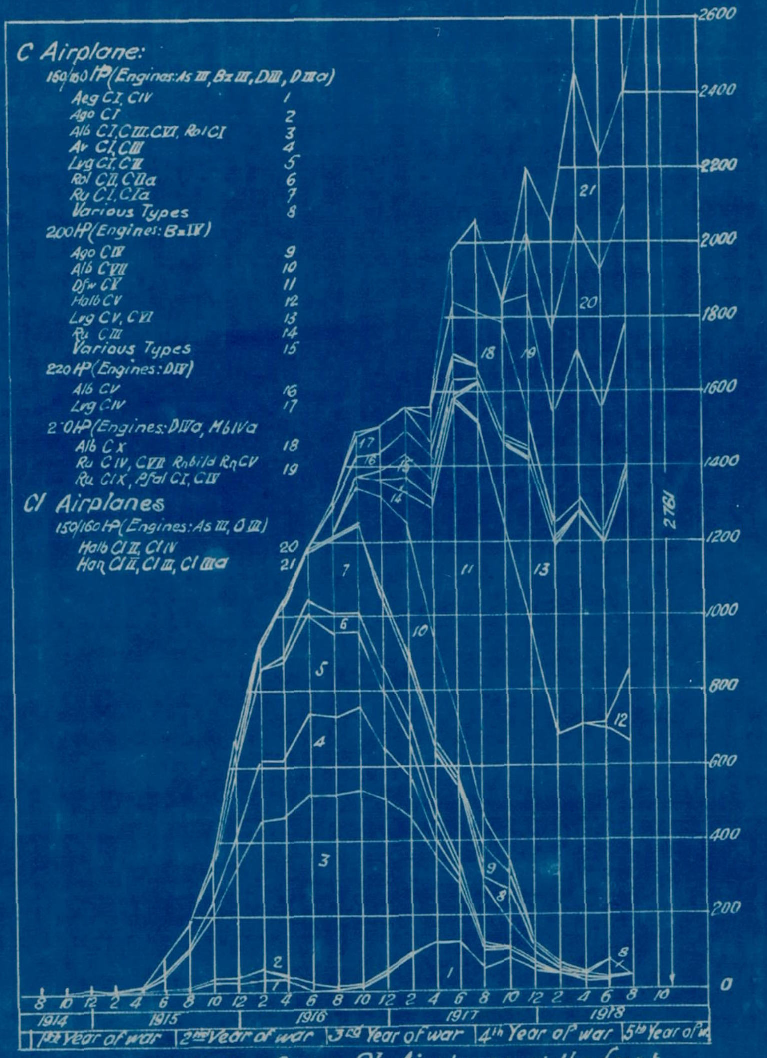


FIG. 14 _ C and Cl Airplanes at the front.

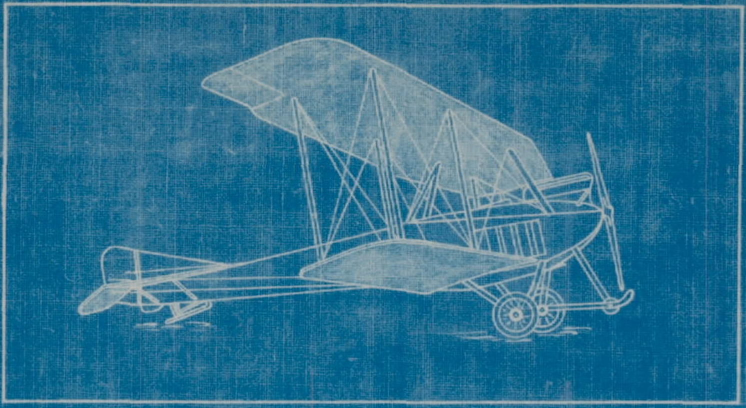


Fig. 4. L.V.G. BI of the Luftverkehrs-Gesellschaft, Johannisthal.

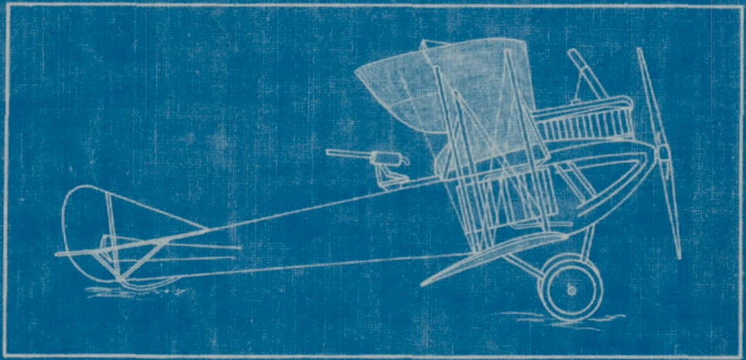


Fig. 5. A.E.G. CI. of the Allgemeinen Elektricitäts-Gesellschaft, Abteilung Flugzeugbau, Hennigsdorf.

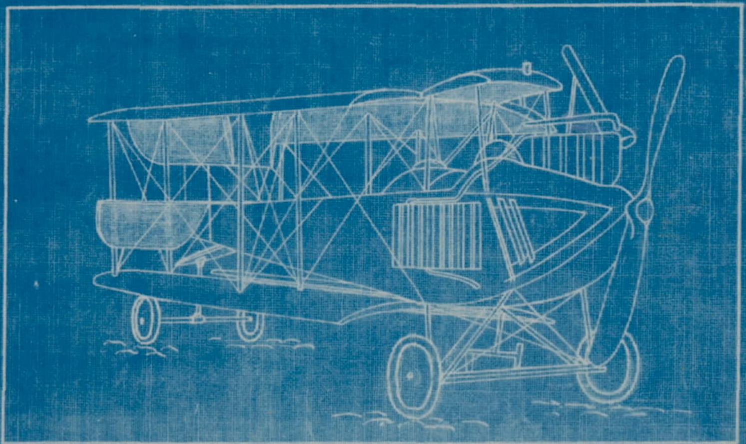


Fig. 6. A.E.G. CI. Wings folded back for the journey.

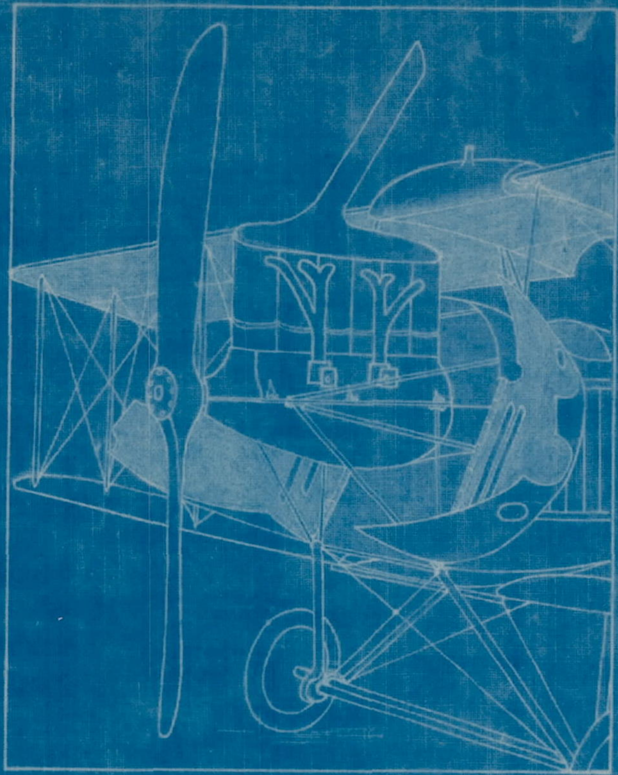


Fig. 7 A.E.G. C I with engine cowling folded back.

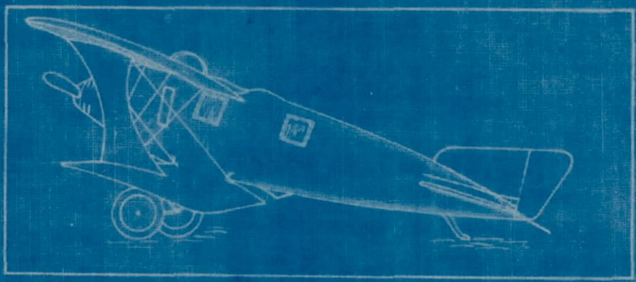


Fig. 8 Roland C II of the Lufttahrzeug-Gesellschaft, Adlershof.

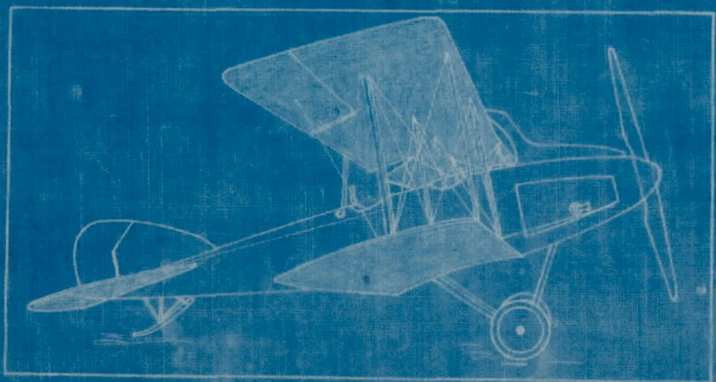


Fig. 9 Albatros - C V of the Albatros-Werke, Johannisthal.

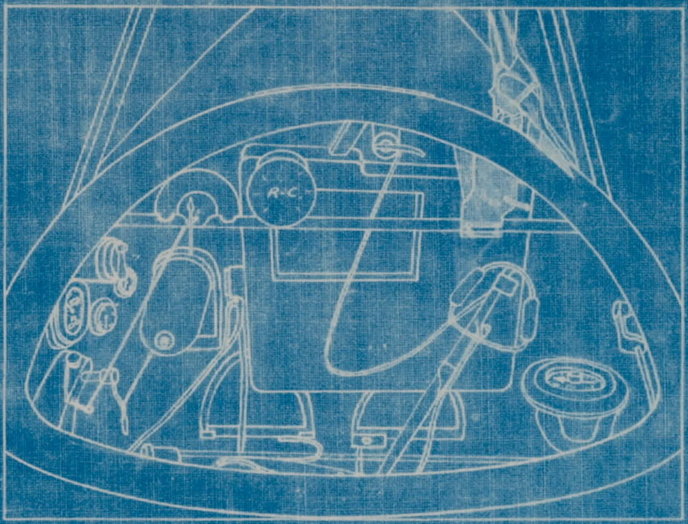


Fig. 10 Cockpit of a C-plane (L.V.G. CV.)

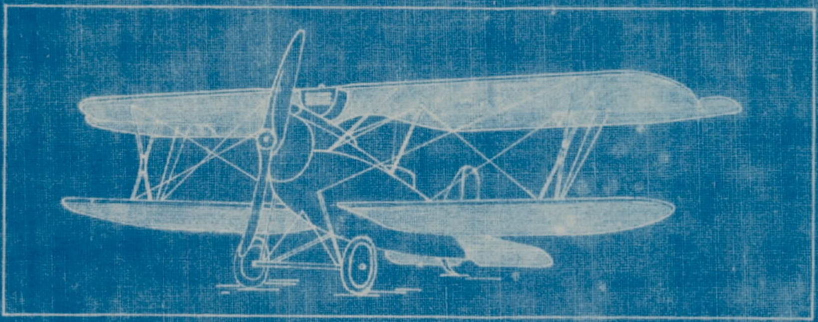


Fig. 11 Rumpler CX of the Rumpler-Werke, Johannisthal.

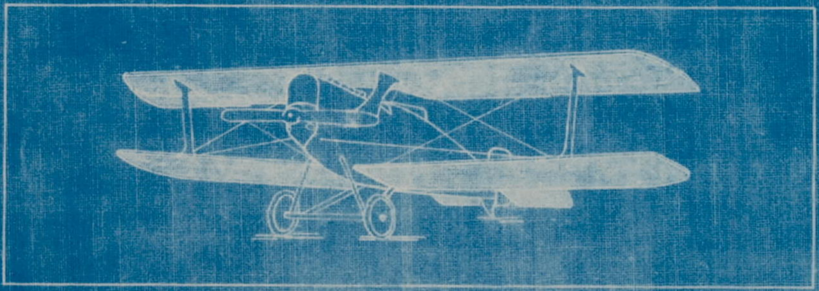


Fig. 12 Hannover CIV of Hannoverschen Waggonfabrik, Hannover.

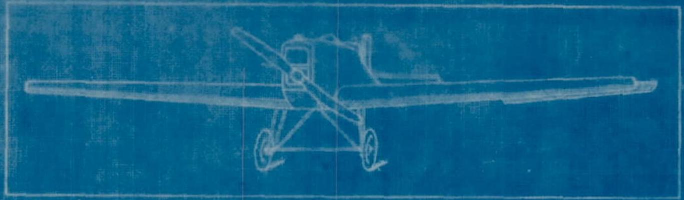


Fig. 13 Junker C.II of the Junkers-Fokker-Werke, Dessau.

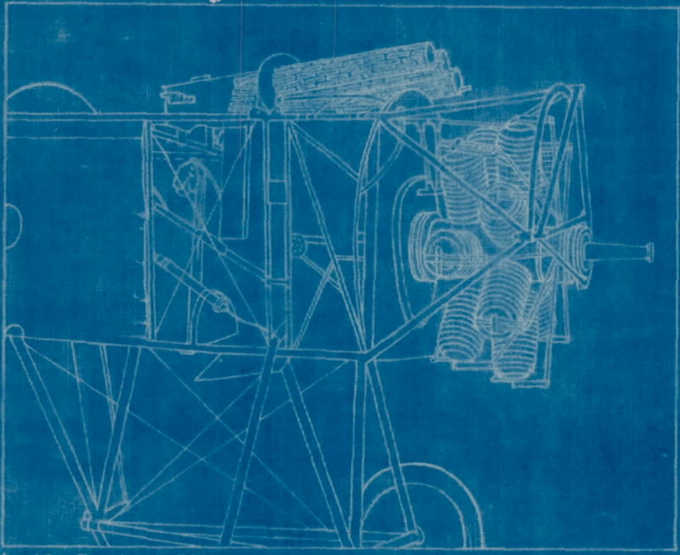


Fig. 16 Fokker E.III with machine gun arrangement.

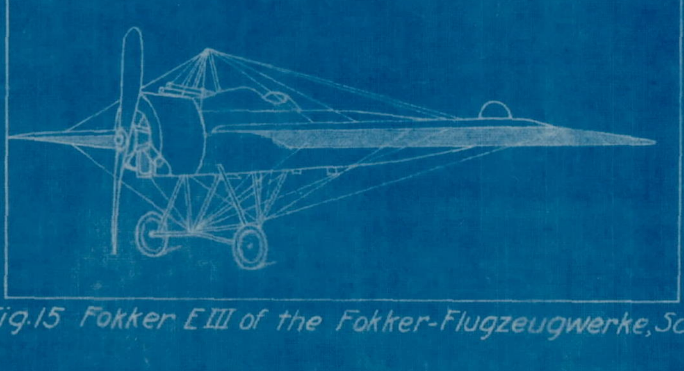


Fig. 15 Fokker E.III of the Fokker-Flugzeugwerke, Schwerin.

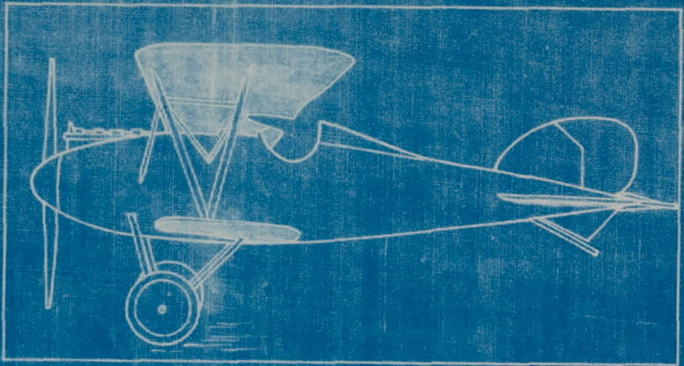


Fig.17 Albatros DV of the Albatros-Gesellschaft für Flugzeugunternehmungen, Johannisthal.

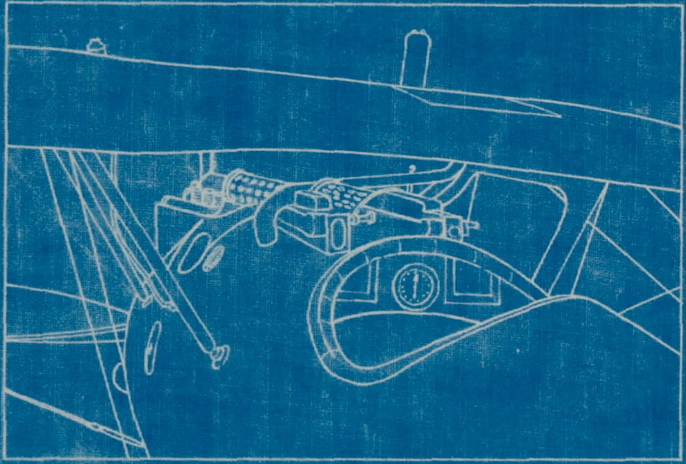


Fig.18 Pilot's cockpit of the Pfalz DIIIa of the Pfalz-Flugzeug-Werke, Speyer.

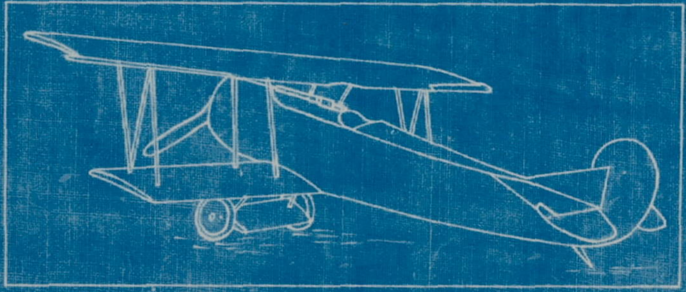


Fig.19 Fokker DVII of the Fokker-Flugzeugwerke, Speyer.

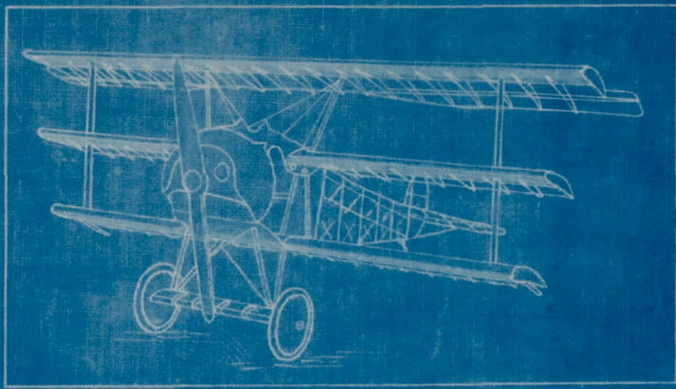


Fig. 20 Framework of the Fokker Dr. I.

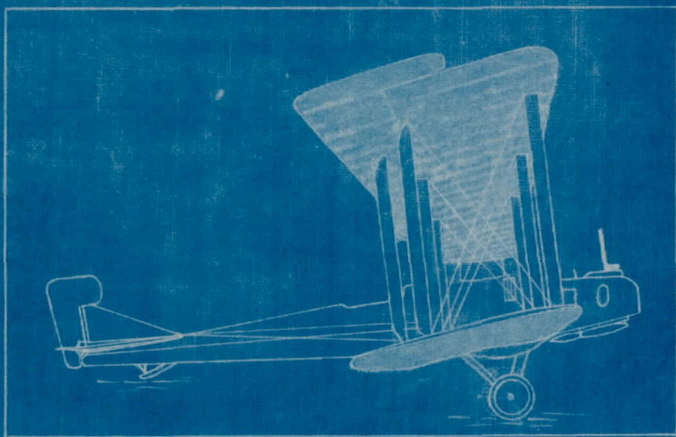


Fig. 22. Go. G IV. of the Gothaer Waggonfabrik, Gotha.

Fig. 23. Gun tunnel in the fuselage of the Go. G IV.

A1000-43

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE

DESIGNED
DRAWN [illegible] 9-30-1920
CHECKED [illegible]
APPROVED W.K. 10/11/20

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FIG. 21 E, D, and Dr Airplanes at the front.

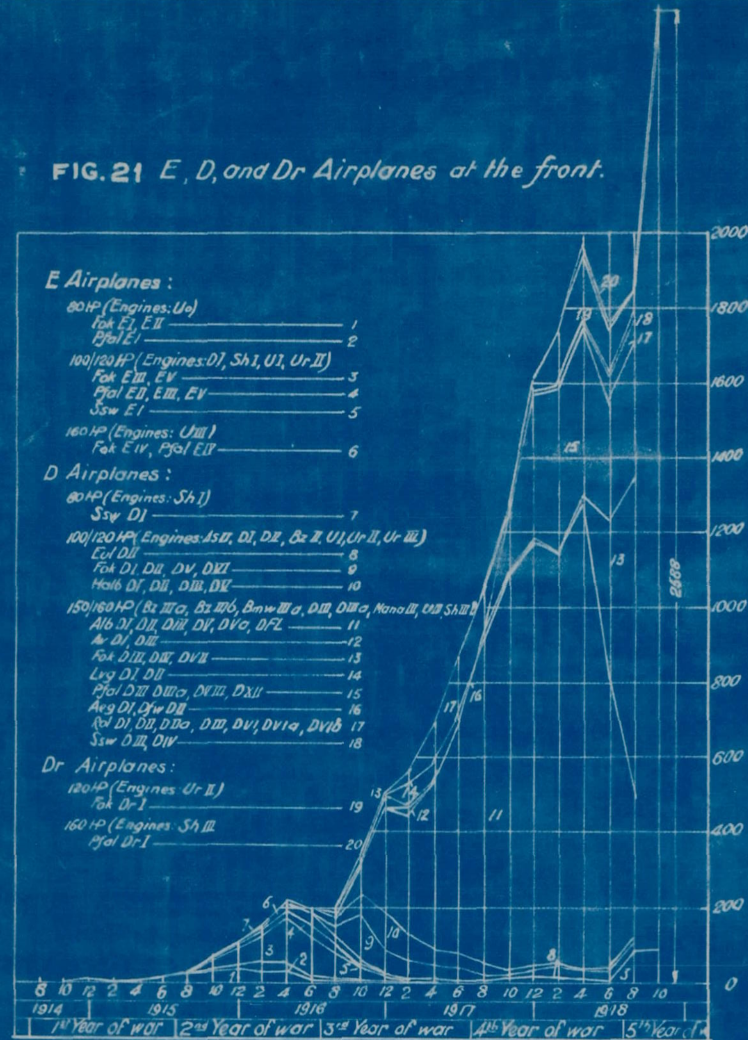


FIG. 27 G AIRPLANE AT THE FRONT

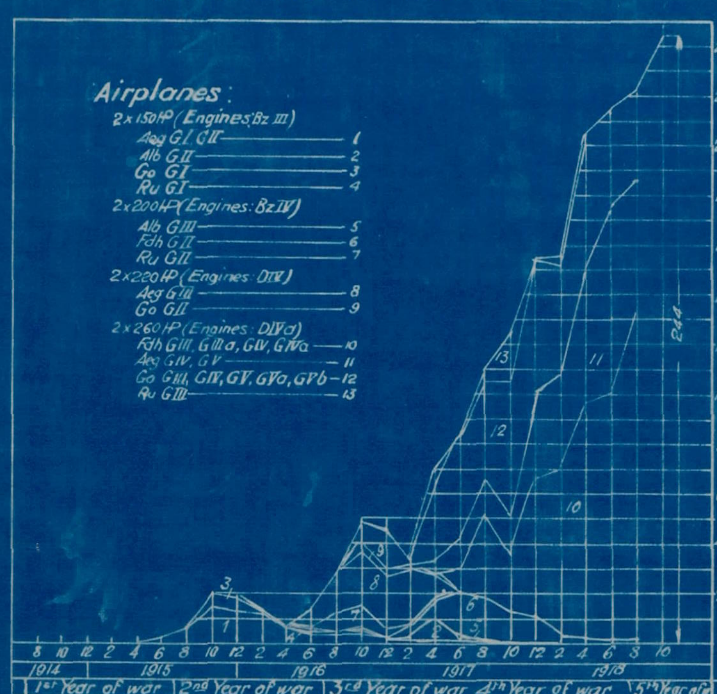


FIG. 38 - ALTITUDE OF FLIGHT OF GERMAN AIRPLANES (EARLY IN 1918)

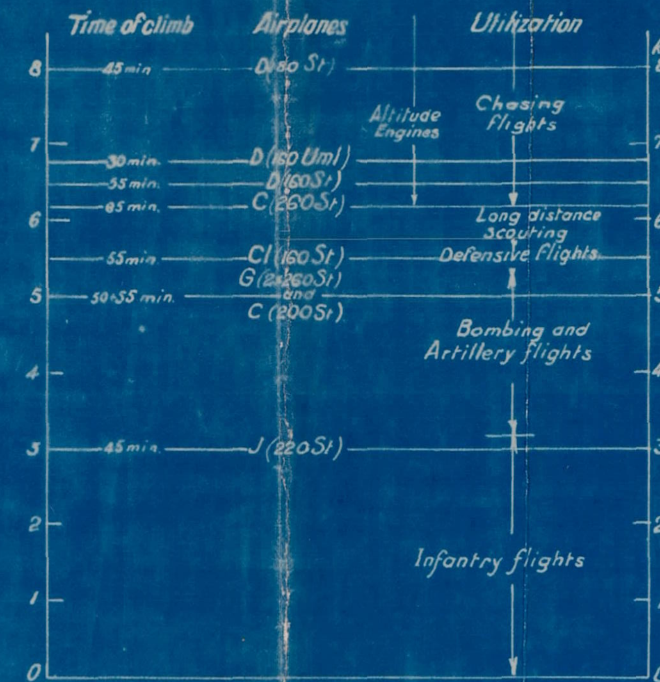
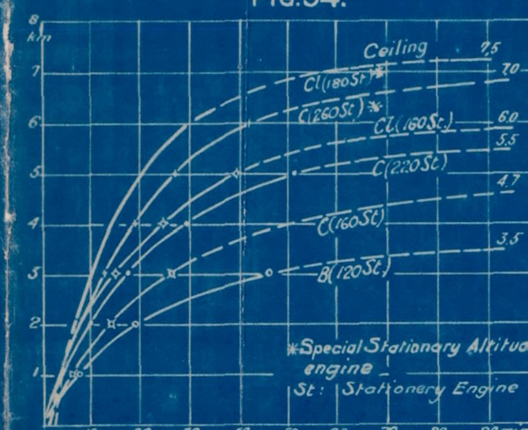
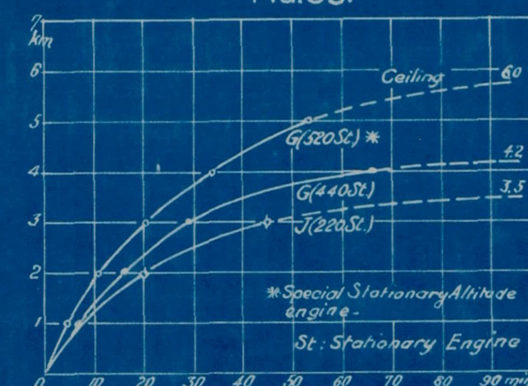


FIG. 34.



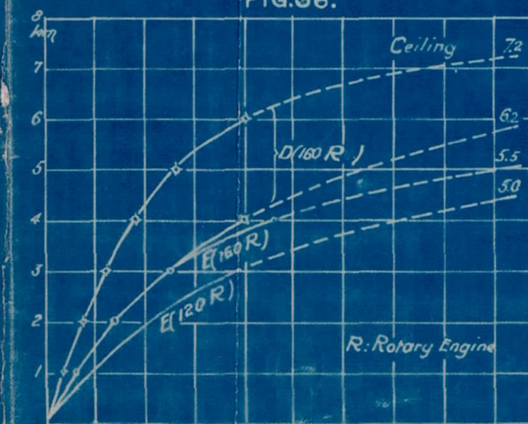
Climbing Results of B, C and Cl Airplanes

FIG. 35.



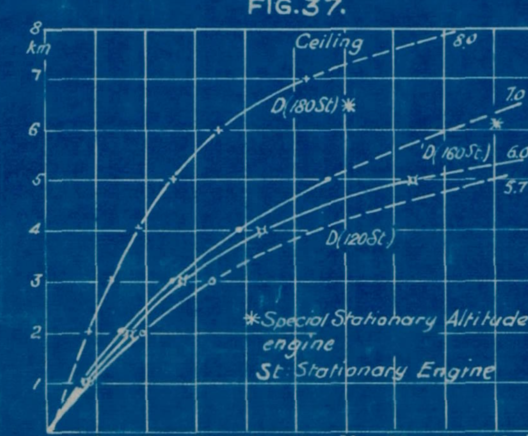
Climbing Results of G and J Airplanes

FIG. 36.



Climbing Results of E and D Airplanes with rotary Engines.

FIG. 37.



Climbing Results of D Airplanes with stationary Engines

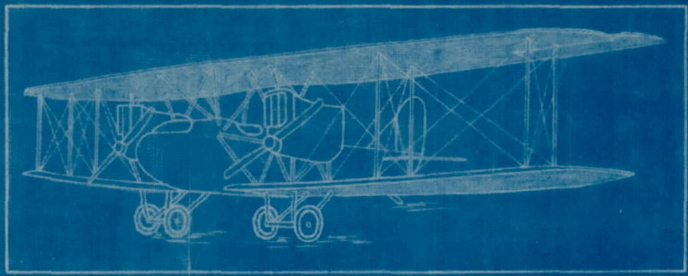


Fig. 24. A.E.G. G IV of the Allgemeinen Elektrizitäts-Gesellschaft, Abteilung Flugzeugbau, Hennigsdorf

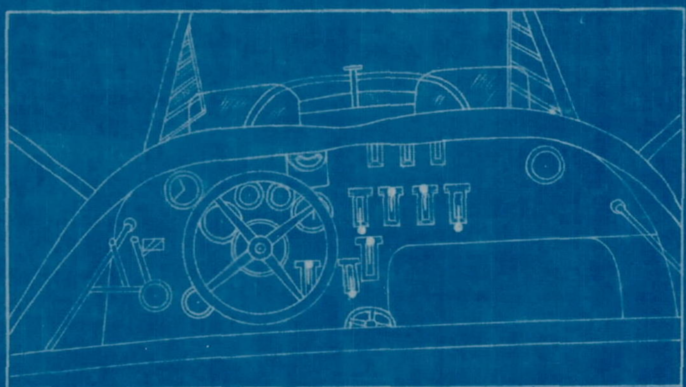


Fig. 25. Pilots cockpit with switchboard on the A.E.G. G IV.

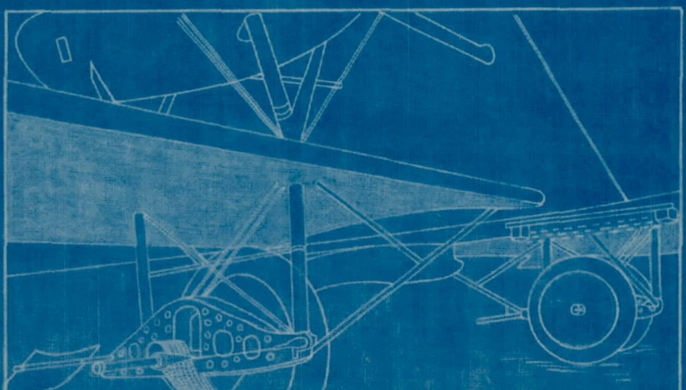


Fig. 26. Undercarriage of the Fdh G III of the Flugzeugbau Friedrichshafen

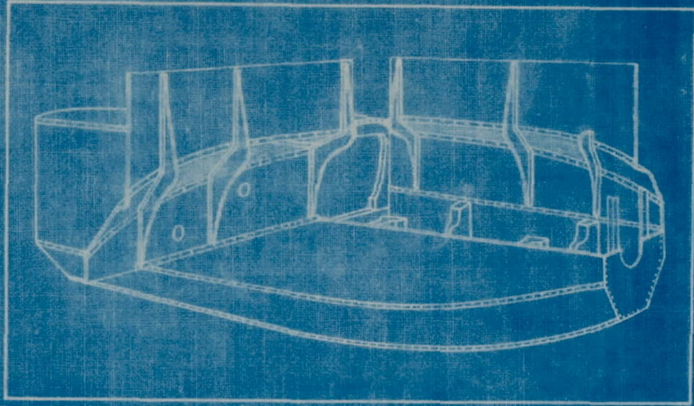
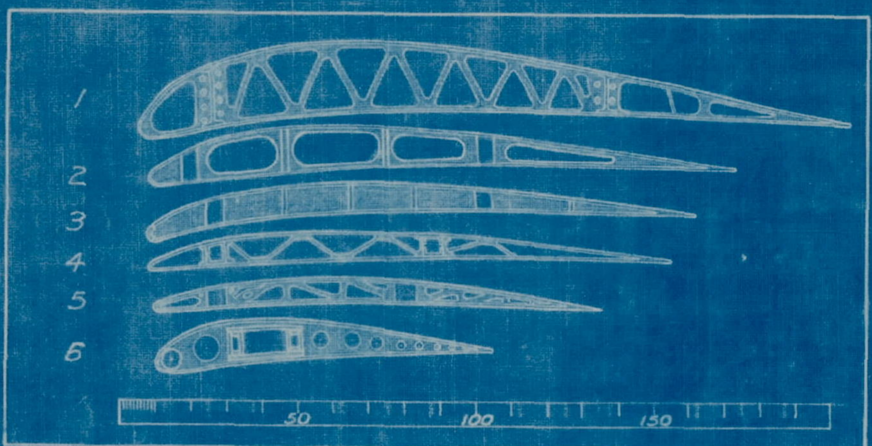
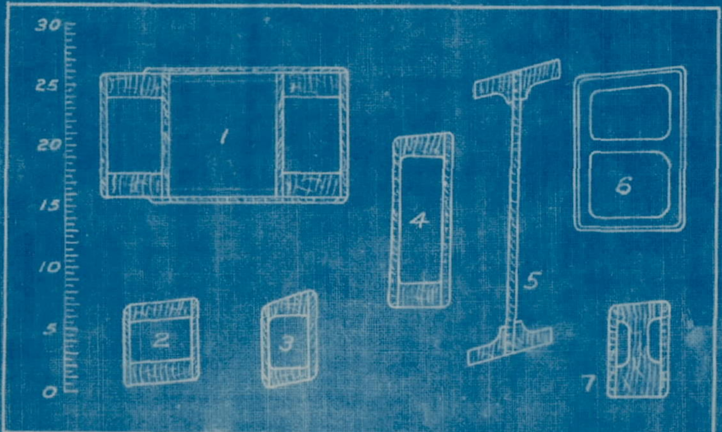


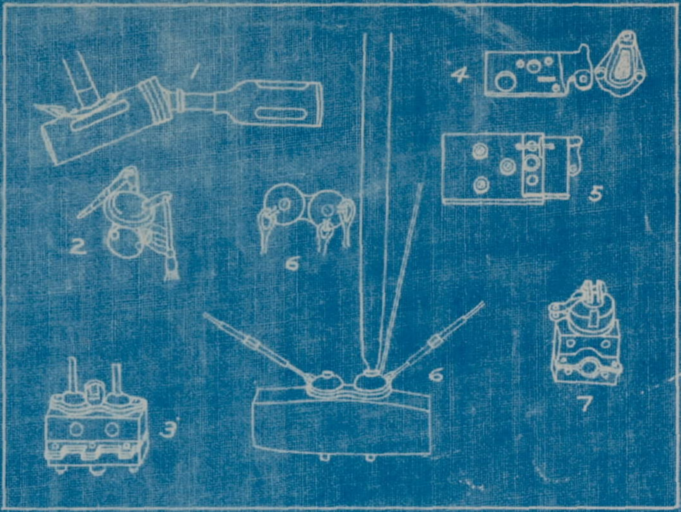
Fig. 28. Armored engine bed opened (engine removed) of the Junker J I of the Junkers Flugzeugwerke, Dessau.



1. Alb. G III. 2. Rol. D II. 3. L.V.G. C IV. 4. Zep. C I. 5. Han C II.
6. Fok. Dr. I.
Fig. 29. Collection of wing ribs.



1. Fok. Dr. I. 2. Alb. D.V. 3. Rol. D III. 4. A.G.V. C VI
5. Alb. G III. 6. Staak. R XIV. 7. Go. G IV.
Fig. 30. Cross sections of various wings spars.



1. Alb.CIII. 2. AEG.CIV. 3. Alb.JI. 4. Ru.CIV. 5. Ru.CIa.
6. Ru.CI. 7. Alb.BI.

Fig. 31. Collection of metal wing fittings.

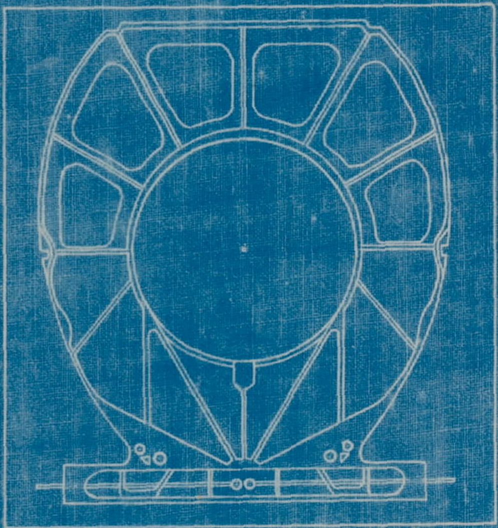


Fig. 32. Section showing point of support for wings of the Rumpler DI of the Rumpler-Werke, Johannisthall.

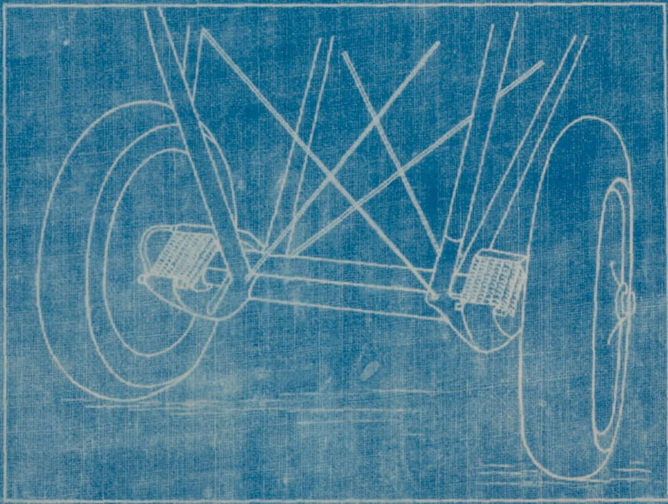


Fig. 33. Undercarriage spiral springs of the A.E.G.