Zap Flaps and Ailerons

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The early history of the Zap development is covered, including work done on the Flettner rotor plane in 1928. Because of phenomenal lift obtained by changes in flow around a cylinder, investigations were begun on improving existing airfoils. This led to preliminary work on flapped airfoils in the tunnel of New York University, and later its application to an Aristocrat cabin monoplane presented to the B/J Aircraft Corporation early in 1932. A chronological record of the reactions of the personnel of the B/J organization to the Zap development is set forth, particularly the questions regarding lift and drag coefficients, effect upon stability and balance, and the operating forces necessary to get the flaps down. The effectiveness of lateral control, particularly with regard to hinge moments and whether the rolling moments were obtained primarily through spoiler action or positive lift increases and the relative percentage of spoiler rolling moments to positive rolling moments, is also included. Comparative data of forces and lift and drag coefficients of several types of flaps are given, with a discussion of the relative practical results. There is a discussion of the practical flying problems in which engineers and pilots are interested, including the effect upon landing and take-off, reactions in a stall, and lateral control below minimum flying speed, as well as the anti-spinning characteristics which have been displayed in actual flight tests.

FOR THE last five or six years, the demand on the part of operators for increased high speed has forced designers practically to disregard the importance of the steadily increasing landing speeds of aircraft. During the same period there has been another influence that has allowed us to still further neglect this factor. It is the fact that modern engines are so reliable and forced landings occur so seldom that their importance has been looked upon with more or less contempt. This was particularly true during the boom days when everybody was using a new engine and when landing speeds were thought of only in terms of getting into recognized airports. Three things have occurred since then, however, that have again brought to the front the importance of low landing speed: First, a very distinct realization that the public was afraid of aviation because of high stalling speeds and the frequent crack-ups with serious consequences. Second, the fact that increased high speeds could not be obtained without increasing still further high landing speeds unless some new aerodynamic development was brought into existence. Third, as speed ranges and wing loadings went up, takeoff run was increased and angle of climb decreased alarmingly.

The Zap development is a successful effort to reduce landing speeds without impairing high speed and thereby to bring about the best overall increase in the efficiency of an airplane with the least added complications. Experimental work on the Zap flap was stimulated by investigations on a Flettner rotor airplane by Mr. Edward F. Zaparka, through the support of the Chrysler Corporation. Because of high lift reactions obtained by the change in flow around a cylinder, the research drifted to a practical investigation of the problem of influencing the flow around an airfoil. The first work was done in a miniature tunnel and was supplemented by larger scale work in the New York University tunnel under the able consultation of Professor Klemin. Subsequently, the flap was installed on a commercial Aristocrat cabin airplane of 165 hp, and flight tests proved that the flap was very effective. These also showed that though lift increases were essential for slow-speed landings, almost equally important was the question of lateral control; Zap ailerons were the result.

In the Spring of 1932, the Aristocrat with Zap flaps and ailerons was presented to the B/J Aircraft Corporation. The author will outline here chronologically the questions and answers that were made and the reactions that he had to the Zap development, because in so doing most of the questions that one would ask regarding Zap flaps and ailerons will be answered.

Our first impression at the B/J plant when we were told that a plane was to be sent down was that it was just another flap airplane and that it would be a waste of time to look it over, particularly because, to our best knowledge, lift coefficients of 0.0044 engineering units were the maximum that could be expected on a simple flap applied to a Clark-Y airfoil. When the airplane arrived at our field, it was observed that it had a split flap and that the ailerons were placed above the wing. This caused considerable apprehension, as it was felt that the ailerons in such a position would surely be blanketed when the plane was brought to a stall, and would not only be inadequate but dangerous. The author was quite reluctant to fly the machine at first, but finally did so, with the expectation of finding that the ailerons would be completely ineffective at 10 to 15 miles above the stalling speed of the airplane. Much to our surprise, they were found to be very effective down to and below the stall of the airplane with flaps up, and materially improved when the flaps were down. After a very short flight, the plane was brought down, with the conviction that it was a bad example of an airplane, but that the flaps and Zap ailerons almost made it a reasonable vehicle. The next step was to investigate the wind-tunnel data which had been carried out by New York University. The results shown in the data presented by Mr. Zaparka were extremely interesting,

[1] President, B/J Aircraft Corporation. Temple N. Joyce was born in Baltimore, Md., on June 27, 1895. He was educated at Baltimore Polytechnic Institute and Lehigh University. He was sales engineer for Truscon Steel Company, of Baltimore, 1915–1916. Applied to Signal Corps for aviation training immediately after declaration of war and was ordered to active duty in May, 1917, receiving commission as first lieutenant and being ordered overseas in November, 1917. At Issoudun, France, was ordered to test department. Received promotion as captain in January, 1919, and last position held at Issoudun was that of assistant chief test pilot. From 1919 to 1925, represented Societe Morane Saulnier in United States and South America, contracting to the United States Army and Navy, Mexico, Argentine, Brazil, and Peru. Entered the employ of the Curtiss Company in 1925 and was Washington representative until 1927. Sales Manager for Chance-Vought Corporation in 1927 and 1928. Organized the Berliner-Joyce Aircraft Corporation in 1928–1929 with Henry Berliner, becoming vice-president in charge of sales. With the acquisition of Berliner-Joyce Aircraft Corporation by North American Aviation, Inc., in June, 1930, was made vice-president and general manager of the newly formed B/J Aircraft Corporation. On May 2, 1932, was elected president of the B/J Aircraft Corporation, and so served until early in 1933, when North American Aviation acquired, through General Motors Corporation, the General Aviation Manufacturing Corporation. In June, 1933, was made executive vice-president and general manager of the latter, supervising consolidation of operations of both companies.

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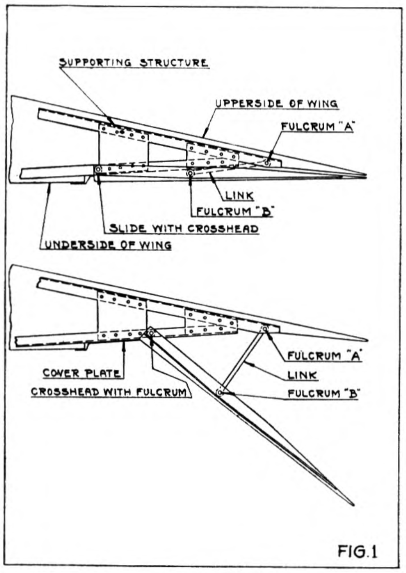


FIG.1

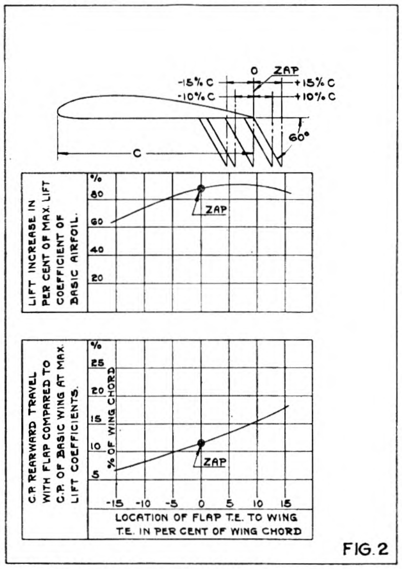


FIG.2

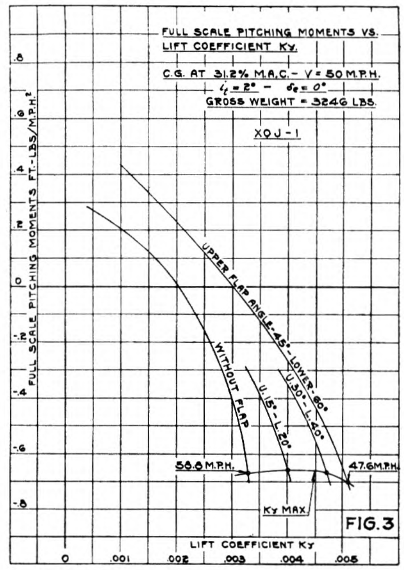


FIG.3

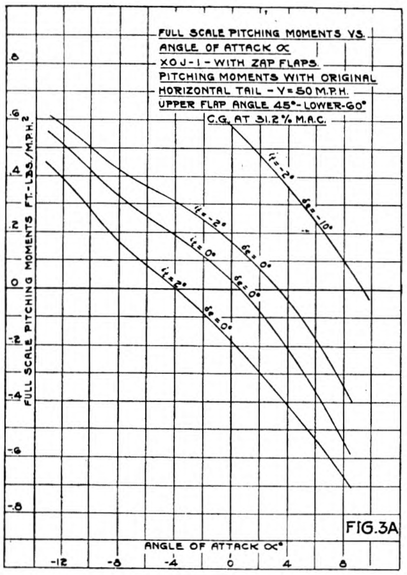


FIG.3A

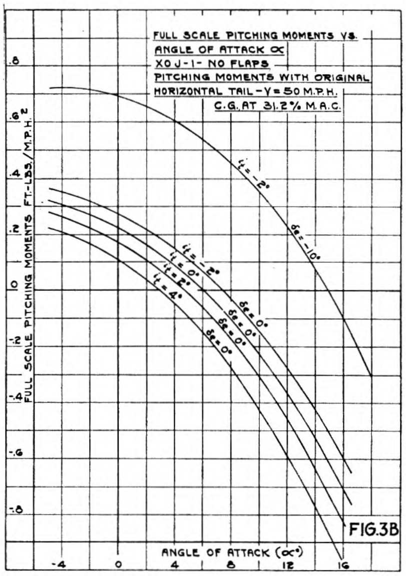


FIG.3B

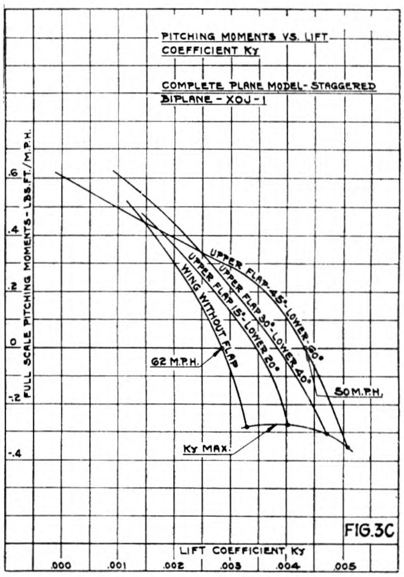


FIG.3C

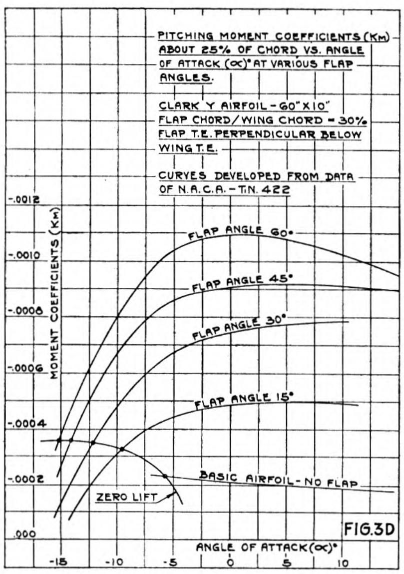


FIG.3D

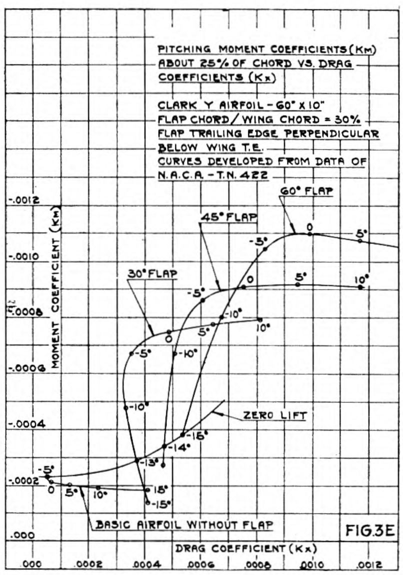


FIG.3E

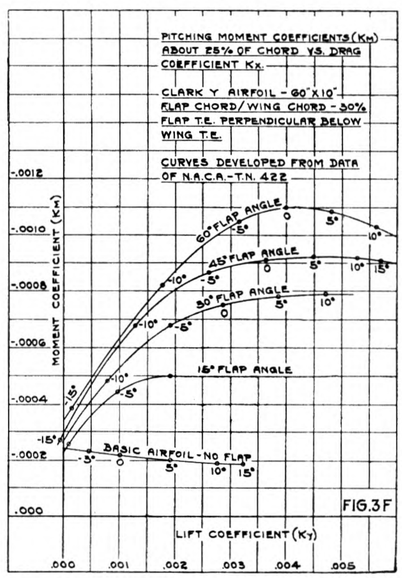


FIG.3F

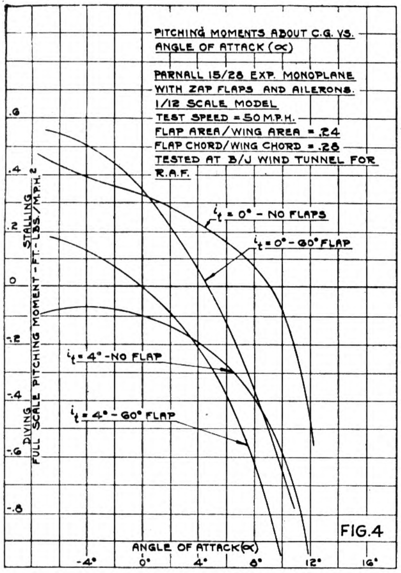


FIG.4

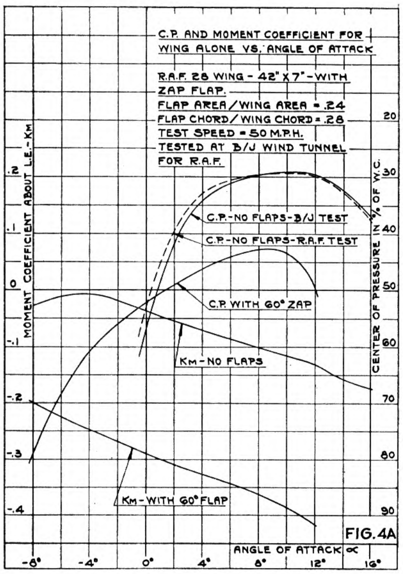


FIG.4A

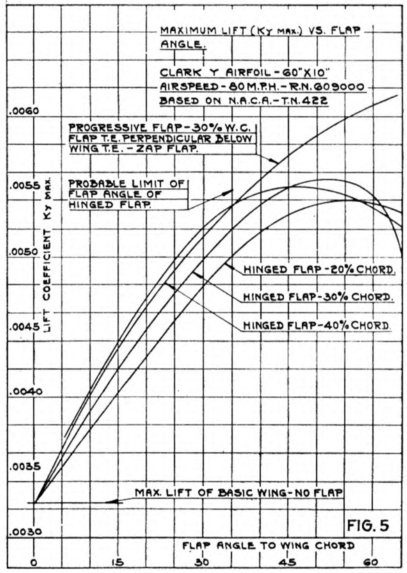


FIG. 5

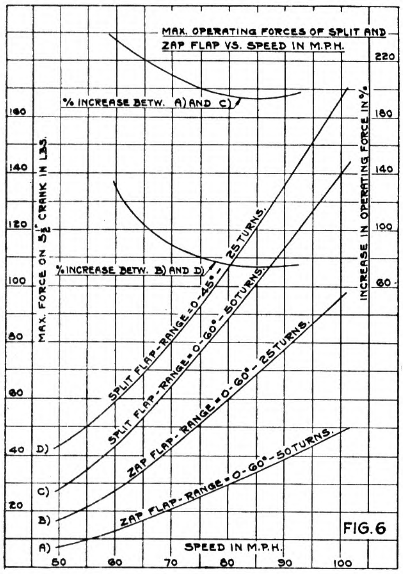


FIG.6

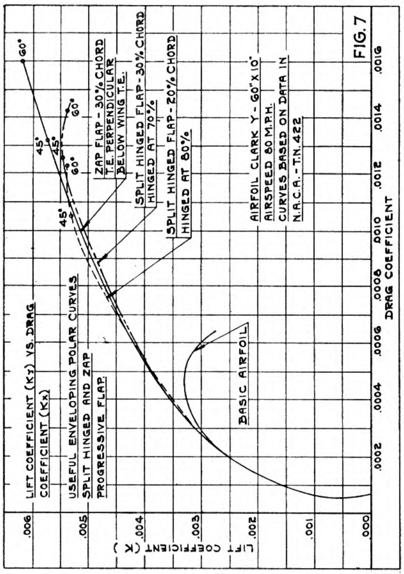


FIG.7

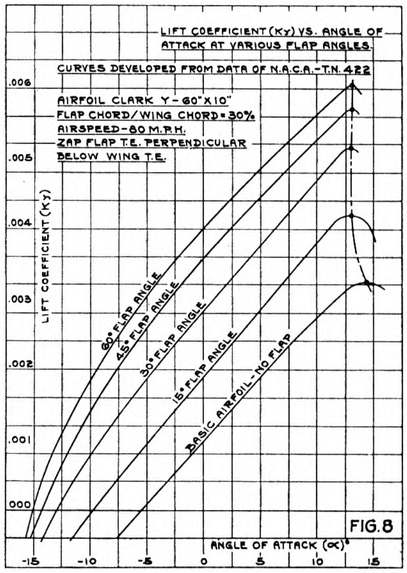


FIG.8

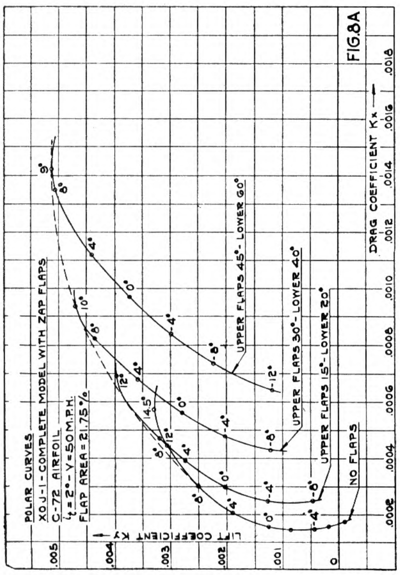


FIG.8A

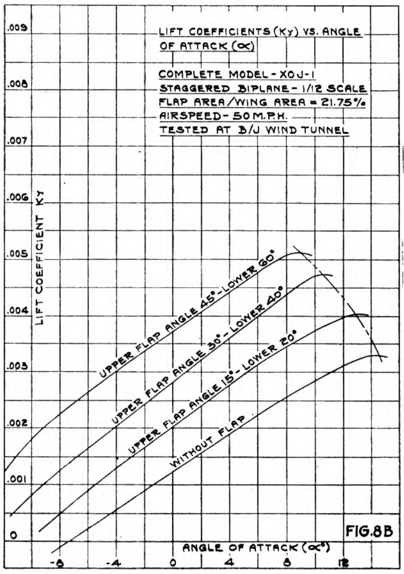


FIG.8B

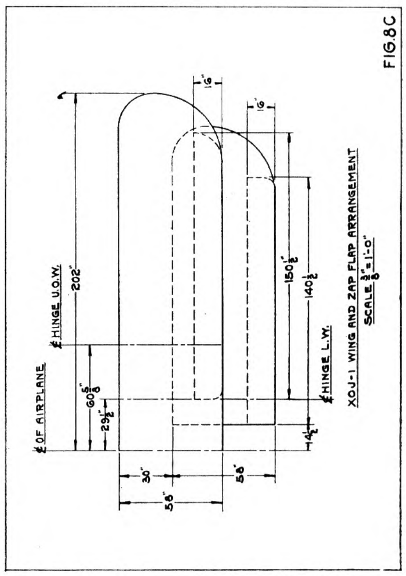


FIG.8C

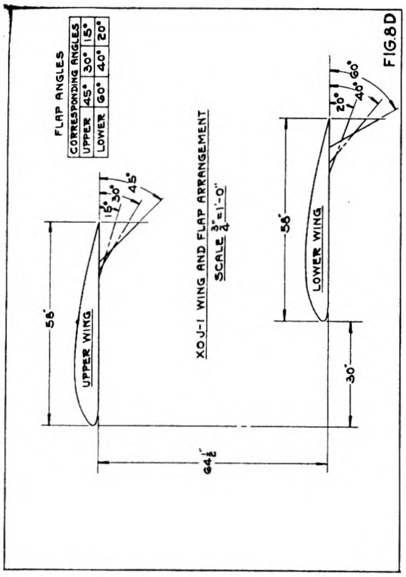


FIG. 8D

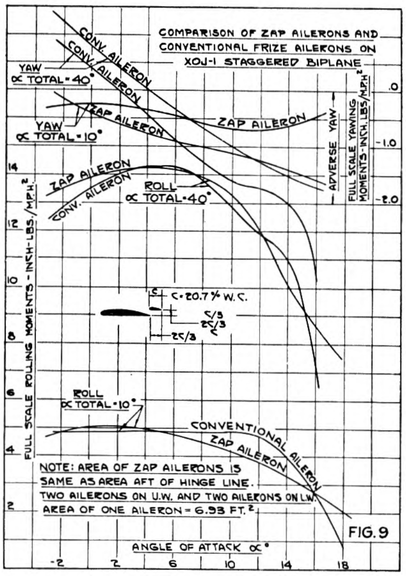


FIG. 9

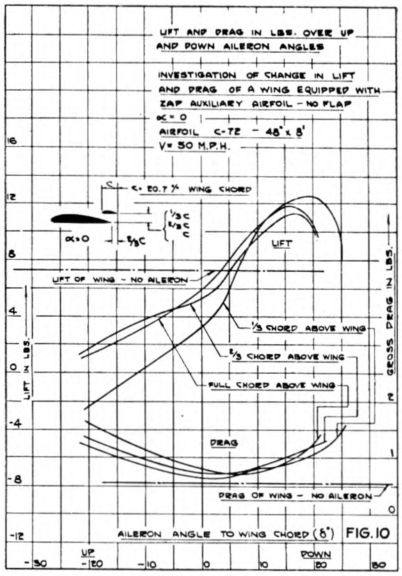


FIG. 10

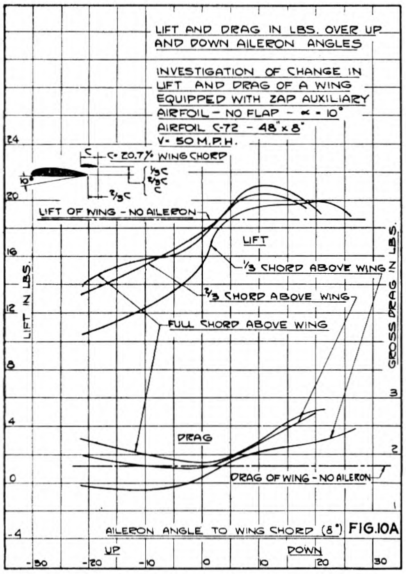


FIG. 10A

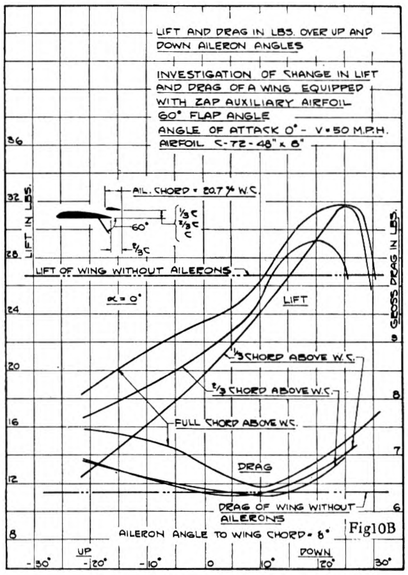


Fig10B

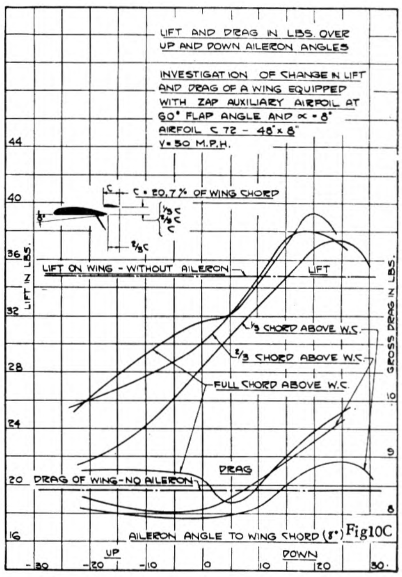


Fig10C

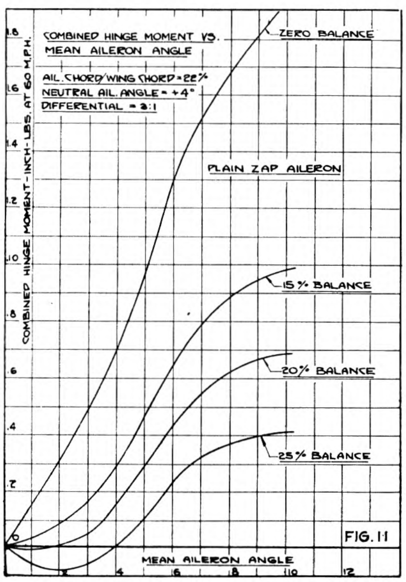


FIG. 11

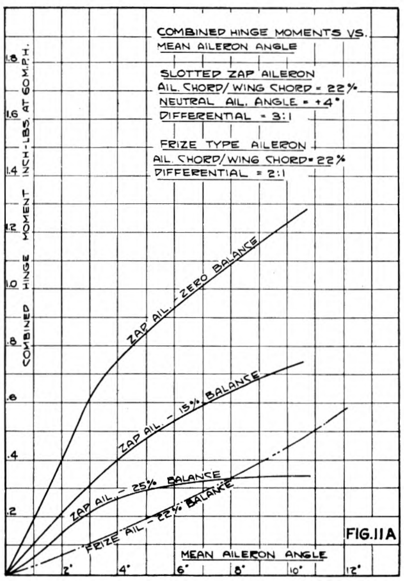


FIG. 11A

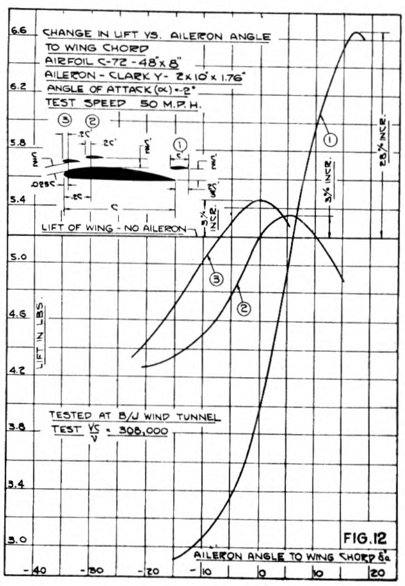


FIG. 12

and the B/J company requested models from New York University, with the idea of checking them in its own tunnel. This was done, and the results of New York University as to lift and drag coefficients were substantiated.

The B/J company had always been interested in slots and flaps, and the Zap development fell into sympathetic hands. We had always felt that the success of slow flying, regardless of how it was obtained, whether with slots and flaps, boundary layer control, or any other means, was dependent upon adequate control at the reduced low speeds. When it was found that an adequate slow-speed lateral-control device was in existence and at the same time did not impair the utilization of the whole span of the wing to obtain maximum lift increases, our enthusiasm for the Zap combination of flap and ailerons was intensified. In previous designs of a simple flap, as stated before, it was known that the maximum lift coefficients did not exceed 0.0044, and when the split flap presented possibilities of 0.0065, an explanation of the theory became necessary. It might be of interest to theorize on what actually takes place in a split-flapped airfoil. With a normal wing, when the simple flap constitutes an actual break in the contour of the upper surface, the increase in lift is primarily due to change in camber, and there is no reaction due to increase of chord or change in flow over the top surfaces other than that which would normally be expected from increasing the camber. With a split-type flap, where the contour of the upper surface of the airfoil is preserved intact, the increase in lift can be divided into three possible heads: First, increase in camber of the bottom surface, which naturally stimulates the flow over the top surface; second, the preservation of the upper surface with the same chord and possibly an increase with certain types of flap movement; and, third, a change in flow over the upper surface brought about by the fact that the split trailing edge and undisturbed upper contour create a combination which causes a further increase in flow over the wing. In the illustrations, the flow reactions back of a simple flap versus the split flap will be seen, and also the effects of moving the trailing edge of the flap forward along the chord. Whether the additional increase in flow over the top of the wing referred to is due to the presence of an area of depression at the trailing edge of the wing caused by the split flap or whether it is due to the displacing of the reversal flow away from the trailing edge so that the bottom surface flow unites with the upper surface flow with less detrimental vortices, is a matter for the theoretical aerodynamicists to thrash out. It is a fact, however, that as the flap is moved forward so that the phenomenon, whatever it might be, is taken away from its influence at the trailing edge, there is an appreciable loss in maximum lift and is best when the trailing edge of the flap is approximately below the trailing edge of the wing, as is the case of the Zap arrangement. Some very interesting data on lift increase devices have been prepared and published by Mr. Richard M. Mock.

With this explanation, the next question was why the airplane did not require greater changes in the horizontal stabilizer to take care of flap up and flap down positions. In Fig. 2 is shown the change in center of pressure brought about by the use of this particular flap movement on an airfoil and the consequence of moving the trailing edge of the flap fore and aft. In an airplane with flaps, the center of pressure travel and effect of changes in angle of downwash must be taken into consideration, and in most cases with the Zap it has a favorable reaction. In Figs. 3, 3A, 3B, and 3C, pitching moments of a conventional naval biplane equipped with Zap flaps and ailerons are shown. Figs. 3D, 3E, and 3F give pitching-moment coefficients for an airfoil, while in Figs. 4 and 4A, the pitching moments of a conventional Zap-equipped monoplane are shown. The net result is that the balance and stability is undisturbed, and increases in tail area or abnormal stabilizer adjustments are not necessary.

The next point of interest, stimulated by the flights of the Aristocrat, was the extremely low operating forces necessary to move the flap down. With a simple flap of the type used on the Breguet observation airplanes in France as early as 1917, the forces necessary to get the flap down were excessive, so much so that the flap could only be deflected approximately 30 deg when usable operating forces and time to operate are taken into consideration. Even if it were deflected to greater angles, the lift coefficients would still be below that of the Zap. (Reference is made to the N.A.C.A. Technical Report No. 422, from which curves on Fig. 5 are interpolated.)

With the straight type of split flap, such as the Wright, where the leading edge of the flap is a fixed hinge, the operating forces are compelled to work against the full aerodynamic load. If the mechanism is of cantilever construction, the forces are prohibitive. If it is of a toggle arrangement, which would have to be some modification of the Zap toggle, without the beneficial effect of the sliding front edge, there again the forces are extremely high and particularly excessive at small angles of flap opening. These forces diminish after the flap has caused sufficient drag to slow the plane a great amount. (See Fig. 6, showing relative loads of Zaps versus straight flap for same angles.) The hypothetical airplane we used in arriving at these figures had a wing area of 309 sq ft, 48 ft 8 in. span, 83-in. chord, Clark-Y airfoil, gross weight of 4600 lb, wing loading of 14.8 lb, power

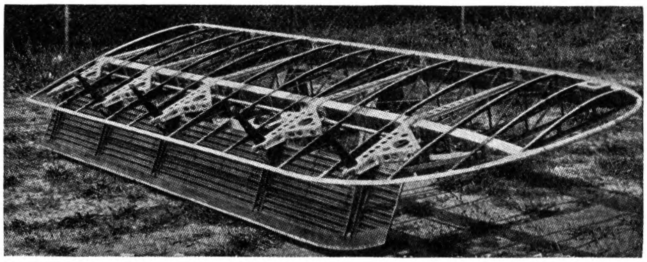


FIG. 13

loading of 10.8 lb, and maximum speed of 150 mph. The flap area for both the Zap and simple flap was 30 per cent of the total area and the flap chord 30 per cent of the wing chord. The total span of flap was 45 ft and total area of flap 93.8 sq ft. Two calculations of forces were made for the simple flap, one a maximum angle of 60 deg and the other a maximum angle of 45 deg. The mechanism for operating the simple flap was the most efficient in our opinion, and the geometry chosen seems to be the one requiring the smallest effort on the operating crank handle. The Zap-flap geometry and operating mechanism are approximately the same as those developed by the B/J company when Zaps were supplied to the XOJ-1 observation airplane for the Navy. A photograph of the XOJ mechanism is shown in Fig. 13, while Fig. 1 shows a schematic view of the Zap toggle mechanism.

When a comparison of lift coefficients is made, it is seen that even though it were practical, from an operating force standpoint, to get the straight hinged flap down to 60-deg angles, in order to obtain the benefit of large drag, the lift would be materially less than the Zap flap, and in fact less than its own 45-deg position. (See polar curves, Fig. 7.)

With the Zap type of toggle arrangement, wherein the leading edge of the flap slides back and the toggle is concealed in the wing in such a manner that one end of it is located close to the center of pressure of the flap and the other fastened to the structure at the top of the rib, it can be seen from Fig. 6 that the number of turns on the operating crank and the forces necessary are extremely low; in fact, with certain types of airfoils, permitting a more favorable geometry of the flap linkage, it will be possible to have actual opening forces.

This phase of the Zap mechanism is extremely important when it is realized that light operating forces have two very important results: First, in that the weight of the operating mechanism can be considerably less, and second, even more important, the fact that in an emergency landing it enables the pilot to get the flap down quickly. In an existing monoplane which has recently been flown in the United States, a straight hinged flap is utilized in conjunction with Zap ailerons for lateral control, and the operating forces are so great as to require 45 turns to get the flap down to 45 deg with a lift increase of only 35 per cent. It can be seen in Figs. 7 and 8 that the maximum lift coefficients of the Zap flap at 60 deg is 0.00615, and also from Fig. 7 that the straight hinged flap has only a maximum lift of 0.00545. These curves were developed by interpolating the data in the N.A.C.A. Report No. 422, because this report did not test the best Zap flap position, but took two flaps on either side of its general location. It must be borne in mind, however, that the angular movement of the flap and the lift coefficients obtainable are intimately connected with the practical results that can be obtained and which of course depend upon the operating forces and the time required to get the flap into action at maximum lift. In Figs. 8A and 8B are shown the lift coefficients for a staggered biplane with the different flap settings on upper and lower wings necessitated by the stagger. Figs. 8C and 8D show wing and flap arrangement.

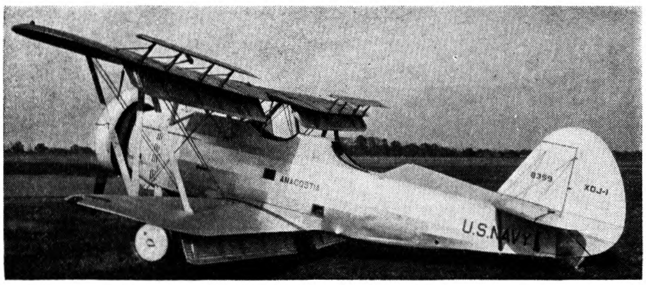


FIG. 14

During the explanation to the engineers of the B/J company and the Zap Corporation when the Aristocrat was first brought to our plant, the discussion of the phenomena surrounding Zap ailerons became quite intense. It had been noted that the ailerons were effective at or near the stall and greatly improved when the flaps were in operation. It was disclosed that the ailerons have a material effect upon the downwash of the wing, and in view of the fact that the flow over the top surfaces is increased by the presence of the split flap at the trailing edge, the ailerons are actually operating in a stimulated flow when the flap is down. These facts were substantiated later when it was found that the ailerons were at their best efficiency when relatively very close to the wing and diminished at a substantial rate when placed too far forward of the trailing edge and too far away in a vertical direction. The original rolling-moment curves presented by the Zap Corporation only represented meager researches as to the proper vertical and fore-and-aft position, aileron-airfoil section, aspect ratio, etc., but the data that were available indicated that the control at low speeds would be excellent. It will be noted in comparing the values of rolling and yawing moments of Fig. 9 that the plain Zap ailerons are approximately equal to the conventional ailerons of the same area. Subsequent tests and present research with modified slotted Zap ailerons show increased rolling moments with considerably lower hinge forces, which are now regarded as not only being equal to but in some instances are superior to conventional Frise types when acting in conjunction with unflapped or flapped airfoils.

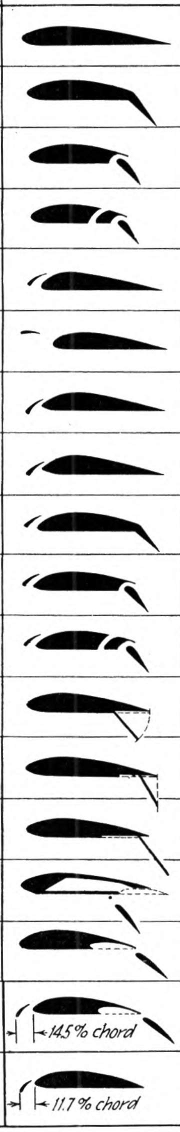
The B/J company was very much interested in determining just how much rolling moment the Zap ailerons were capable of producing, how much of this was due to lift increase, and how much to spoiler in contrast with conventional ailerons. In order to determine this, our first tests consisted of an 8-in. by 48-in. airfoil on which a Zap aileron was superimposed throughout the span with the idea of determining the actual flow phenomena that took place when the ailerons were deflected through positive and negative angles. It was found that when the ailerons were suspended independently of the wing and were deflected through positive angles, there was a large increase in lift induced in the major airfoil as well as the lift created by the aileron itself due to its own airfoil action. On Figs. 10, 10A, 10B, and 10C are some of the results of these tests with the 8-in. by 48-in. airfoil showing the lift increases with positive angle and its spoiler action due to negative angles, as well as the drag increases or decreases. In these figures the drag of these auxiliary airfoils across the entire span for various angles of attack of the main airfoil is also shown. This increase in drag will be in the nature of approximately 1 per cent loss in speed of the airplane when the ailerons cover 50 per cent of the semi-span. In the application of the Zap ailerons to a conventional Navy biplane, shown in Fig. 14, where there was no particular attempt made to have a clean installation, the loss in speed was 1 per cent plus. There is additional research now being done on this type of aileron to absolutely determine the optimum fore-and-aft position and the best combinations of this with vertical location as well as the proper airfoil shape, the correct aspect ratio, the best shape of wing tip, and the proper relation of aileron chord to main airfoil chord. In Fig. 11 the hinge moments of a straight Zap aileron are shown, which indicates that for high-speed airplanes there will be excessive stick forces (but which are quite practical on slow planes of the private class). It is interesting to compare the hinge moments of the conventional unbalanced aileron, plain Zap, and slotted Zap ailerons in Figs. 11 and 11A. All Zap ailerons are quite sensitive to vertical and horizontal location, depending to some extent on the wing section, and their neutral setting is most important. The slot of the aileron is quite different from that which is used on a wing due to its proximity to the wing upper surface, and its form and setting must be carefully determined. In Fig. 12 is shown the effect of placing the aileron in several fore-and-aft positions on the forward part of the wing as compared to the best position ascertained so far by us.

It might be interesting to bring out the following facts to differentiate between the Zap ailerons and the conventional and floating types. Previous to the development of the Zap aileron, any attempt to use a trailing-edge flap was immediately handicapped by the fact that from one-half to two-thirds of the span was used for lateral control, thereby diminishing the available maximum lift increase. When evaluating their respective merits with any type of lateral control, there are two conditions of flight that must be considered: control above the stall and control below the stall. With the conventional aileron, if the plane is approaching a landing in a glide above the stall but very close to the maximum lift, and a wing is unavoidably dropped, when the aileron is moved to a positive angle with the idea of picking up the low wing, several conditions are to be observed. Any small deflection of the aileron is reflected in a change in the lift on the major airfoil. This is of distinct advantage, because small aileron surfaces can be made to produce a rather substantial rolling moment by influencing the flow over the major airfoil. The conventional aileron, however, is at a disadvantage in that a large movement of the aileron might create a resultant angle of attack that would be beyond the critical angle and cause the wing to stall and further accentuate the dropped-wing condition. Simultaneously with this, due to the unfavorable yawing moment, the wing tends to rotate backward and still further decreases the lift with the possibility of entering a spin. Any further positive movement of the aileron only aggravates the stalled condition from a standpoint of flow over the major airfoil and at the same time induces further unfavorable yawing.

We will compare this with the floating aileron and later the Zap. In the condition where the airplane is approaching the ground, close to the point of maximum lift, but with floating aileron, if the wing is inadvertently dropped a positive deflection of the floating aileron will create an increase in lift, but only an amount equal to the lift generated by an airfoil of that particular aileron area and section at that particular angle of attack. There would be no induced flow over the surface of the major wing. In designing such an aileron, this would have to be taken into consideration, and the aileron would have to be quite large so as to produce within itself a practical rolling moment at the reduced speed of flight brought about by the use of flaps or any other slow-speed device. The resultant aileron, by reason of its size, would then present very difficult structural features, as well as added weight and drag. This type of aileron naturally would have no bad effect of aggravating the stalled attitude of the dropped wing either when the airplane was coming in slightly above the stall or beyond and would have still further the advantage, by reason of the angle of its lift vector, of a favorable yawing moment that would tend to pull the low wing forward and increase its velocity and consequently its lift.

With the Zap aileron, the first reaction is that it is just another airfoil suspended above the wing, of which there have been numerous designs in the past. The original Curtiss type was mounted at a considerable distance from either surface of the wing, and through its angular movements produced a workable rolling moment. These ailerons went out of existence because of the fact that they were inefficient. They induced no increase in lift over the major airfoil sections, and if they were large enough to produce a usable rolling moment, their drag, mechanism, and structural features were decidedly objectionable.

The Zap aileron, by reason of its proximity to the upper surface of the wing, naturally affects the flow over the top surface. Analyzing the several conditions, as was done in the case of the conventional floating ailerons, we find that if the airplane is being brought in close to the point of maximum lift and the wing is inadvertently dropped with a positive movement of the Zap



	Angle of lift increasing surface to basic airfoil	Flap chord in per cent of basic airfoil chord	Max. lift coefficient C_L max.	Speed range factor $C_L max./C_D min.$	L/D at max lift ②	Angle of attack of basic airfoil at max. lift	Per cent improvement in lift: Over plain airfoil ①	Per cent improvement in lift: Over simple flap	Per cent improvement in speed-range factor: Over plain airfoil ①	Per cent improvement in speed-range factor: Over simple flap	Reference, N.A.C.A. report
Plain basic airfoil ①			1.291	85.0	7.6	15°					T.R. 427
Simple flap	45°	30%	1.950	128.2	4.0	12°	51%		51%		T.R 427
Slotted flap with cover plate	45°	30%	1.980	120.5	4.0	12°	53%	1.5%	42%	None	T.R 427
Double slot and flap	45°	30%	2.442	117.5	4.0	16°	89%	25%	38%	None	T.R 427
Fixed slot, cut in basic airfoil			1.772	73.8	5.3	24°	37%	None	None	None	T.R. 427
N.A.C.A. fixed auxiliary airfoil, ahead of basic airfoil ③	0°	14.5%	③ 1.705	104.5	3.5 Approx.	24°	32%	None	23%	None	T.R. 428
N.A.C.A. optimum fixed slot ③			③ 1.648	76.4		24°	27%	None	None	None	T.R. 400
Handley Page type automatic slot ③			③ 1.632	③ 114.2 129 ⑤		28°	26%	None	③ 34.5% 52% ⑤	None	T.R. 400
Front slot and simple flap	45°	30%	2.182	91.0	3.8	19°	69%	12%	7%	None	T.R. 427
Front slot and slotted flap	45°	30%	2.261	93.2	3.8	19°	75%	16%	10%	None	T.R. 427
Triple slot and flap	45°	30%	2.600	87.3	3.8	20°	101%	33%	3%	None	T.R. 427
Split flap, rotated down, no backward movement	50°	30%	2.16	138.5	4.3	14°	70%	10.7%	63%	8%	T.N. 422
Split flap, trailing edge moved vertically downward (Zap)	60°	30%	2.35	150.8	3.7 Approx.	13°	85%	20.5%	77%	17.5%	T.N 428
Split flap, hinge point moved back to 90% of chord	54°	40%	③ 2.222	③ 142.2 161 ⑤	3.8	13°	75%	14%	③ 67% 89% ⑤	③ 11% 126% ⑤	T.N. 422
Hall wing, front slot closed	48°	34%	2.08	138.8	3.6	13°	64%	6.7%	63%	8.1%	T.N. 417
Fowler wing, projected (area increased approx. 31% over basic airfoil) ③	40°	40%	③ 2.422	③ 155.3 203 ⑤	4.25	15°	90%	24.3%	③ 83% 140% ⑤	③ 21.2% 59% ⑤	T.N. 419
Fowler wing with N.A.C.A. 22 slat and round nose of basic airfoil	Slat −40° Flap +40°	Slat 14.5% Flap 40%	③ 2.49	③④ 137 ⑤ 199	3.76	21° to 25°	96%	28.1%	③④ 61% ⑤ 134%	③ 7% ⑤ 55%	T.N. 459
N.A.C.A. 22 slat on plain wing with rounded nose	Slat −45°	Slat 14.5%	③ 1.78	④ 97.7 ⑤ 114.2	4.8	30°	40%	None	③④ 15% ⑤ 35%	None	T.N. 459

FIG. 15

(This table was compiled by Richard M. Mock and was published in *Aviation*, May and July, 1933. The Reynolds number for all tests is 609,000, which corresponds to about one-third that for an ordinary small airplane at landing speed (T.R. 400). ① In comparing properties of modified sections with the plain basic section, the coefficients used in each case were obtained under similar test conditions. Drag coefficients were taken with slot closed (if movable) and with flap neutral. ② A low value of L/D at maximum lift indicates a steep glide angle and consequently a short landing. An L/D of 8 corresponds to a gliding angle of approximately 7 deg, and a value of 3.5 means about 16 deg (T.R. 428). ③ Based on total wing area; lift-increasing device extended and projected on original chord line. Actually this area is structural area necessary and forms the basis for the comparison with the simple flap. ④ With slat and flap retracted, the airfoil is not perfect, having a drag coefficient of 0.0182 compared with 0.0156 for the plain airfoil. ⑤ Based on contracted area.)

aileron, there is not only created a rolling moment by the increase in lift on the aileron acting as an airfoil section alone, but there is also an induced lift on the major airfoil, together with a yawing moment that is slightly less than the conventional aileron. (See Fig. 9.) At or below the minimum flying speed at which an unflapped airplane can fly, by reason of the fact that the Zap ailerons are used in conjunction with Zap flaps, the aileron is actually operating in an area of stimulated flow, and consequently produces favorable rolling moments at speeds far below the speed at which a conventional-wing airplane can be controlled with Frise or floating types. Even without the effect of stimulated flow due to the flap, the ailerons produce rolling moments comparable with conventional ailerons per unit of area. It must again be borne in mind that conventional ailerons cannot be used efficiently with flaps located across the entire span of the wing by reason of the fact that they would be blanketed by the flap. If they are used, the flap can only occupy the inner portion of the span. At the reduced flying speed accomplished with the aid of any slow-speed device which is below that of the minimum flying speed of an airplane without flaps, the conventional aileron is all the more ineffective by reason of the fact that it is operating in a reduced flow of air, whose velocity is equal to that of the plane and not the stimulated flow over the top surface, as is the case with the Zap type. This penalty also applies to floating ailerons, which, however, do have the overall advantage of permitting the utilization of the whole trailing edge for flap. Preliminary investigation indicates that Zap ailerons will also be quite interesting in any slot and flap application in the future.

At this point there might be given some of the practical reactions had in flying Zap-equipped airplanes. There is no doubt that reduced minimum speed, with adequate lateral control and good inherent stability, will materially lessen the fatal crashes in aviation. In the majority of instances, fatal crashes occur from flying too slowly or gliding into a forced landing immediately after motor failure. The loss in lift at a speed just below the minimum naturally causes the airplane to mush, with a consequent increase in the resultant angle of attack, which, when beyond the critical angle, results in a critical loss in lift and altitude. The reason for flying slowly is brought about by the fact that the pilot is forced to do so in order to get into a given airdrome over surrounding obstacles. Realizing that the modern airplane glides so flat and so fast, as is becoming more evident each day with the cleaning up of designs and increasing of wing loadings, and in attempting to consume the smallest possible amount of airdrome while in the glide, and also after leveling out, the pilot invariably brings the plane in as close to the point of maximum lift as he feels that he is capable of doing—and the better the pilot, the more likely he is to feel that he can play close around the stall point. If a sudden gust or if inattention on the part of the pilot inadvertently brings the flight attitude over the critical angle, a crash is likely to result, and the impact with the ground must be very close to the minimum flying speed of the ship, which, as assumed, is already very high. The pilot cannot put his nose down after coming in over an obstacle and pursue a steep angular path to the ground at a safer angle of attack because of the large pick-up in flying speed. This increase in speed would prolong the path of flight tangential to the ground, which almost invariably results in a high-speed two-point landing. With a Zap-equipped airplane, it is not necessary for the pilot to bring the airplane in close to the point of maximum lift, as far as excessive utilization of the airdrome is concerned. The Zap-equipped airplane, because of its high lift and drag, can be brought in along a flight path that is so steep as to permit only a small utilization of available airdrome distance. Even when the nose is put down at a 45- to 50-deg angle, the increase in speed is small, and when the airplane is leveled out, the drag causes it to decelerate very rapidly and the high lift permits a slow minimum speed when it drops on the ground. It might be pointed out that the steep approach to the ground is a disadvantage from a standpoint of the technique required in landing. This would be admitted if it were not for the fact that the increased lift permits a speed along the flight path so materially reduced that from actual experience there have been no adverse comments by pilots. There have been instances of airplanes being equipped with airbrakes, but without the necessary increases in lift. The result has been that, as the airplane must be dived at the ground at a sharp angle and at an unreduced minimum speed, the rate of descent is so great as to be quite disconcerting. The reaction is caused by the necessary sharp flaring action close to the ground and the short time interval, aggravated by the high vertical velocity. With the modern airplane whose cleanness has gone so far beyond the airplane of several years ago, the addition of the drag imposed by a flap does nothing more than bring the gliding angle back to what we were accustomed to and eliminates the bad floating characteristics. If an airplane were infinitely dirty from a drag standpoint and had a high wing loading and flaps in addition, it would be conceivable that the airplane would have to be dived at the ground at a 50- to 60-deg angle, and the transition from this attitude to the 12- to 15-deg angle of attack for landing would quite complicate the technique of landing.

Here we come to the problem that is often advanced by the automatic-landing proponents. It is the author's opinion that flying will not reach popular enthusiasm sufficiently to warrant a large industry until the human element of flying has been reduced far beyond what it is today. The place where the greatest human judgment is necessary is in that transition which takes place when the airplane comes in at a given negative angle in a glide and must be leveled off with the angular attitude changing to 12 to 15 deg positive. It would be most desirable to build an airplane in which the pilot could wind a crank adjustment to a point where an indicator would designate "landing attitude," pull back his throttle, and let the airplane do the rest. There are certain things, however, which make this difficult at this time, and under certain commercial operating conditions, they will be difficult to meet in the future. This is qualified, however, by considering only existing practical high-lift devices. Rates of descent beyond 12 to 15 ft a second are going to be difficult to take care of except in a very awkward type of landing gear. A rate of descent of 12 ft a second at or near maximum lift can only be accomplished at the present time with a lightly loaded airplane of clean lines and with flaps or with slots and flaps. As the wing loading is increased, the velocity along any given flight path very adversely affects the rate of descent, and the total overall L/D of the airplane with retracted flaps must be very good in order not to have too steep an angular gliding attitude for the particular wing loading. With a lightly wing-loaded airplane, somewhere under 10 to 12 lb per sq ft, and a good L/D, it is perfectly possible today to build a private or sport-type airplane with Zap flaps that could be mushed into a landing without the necessity of the pilot redressing by touching the controls. When we get into the commercial transport field where high wing loadings are imperative from a standpoint of speed and pay-load efficiency, it will be essential that the pilot use quite an amount of judgment in approaching the ground and in the following leveling off for landing. This condition will continue, in my opinion, until such time as we are able to create much higher lift coefficients than are practical today.

In closing it might be added that as one becomes more experienced with flap airplanes, he arrives at the conclusion that the ability to raise and lower the flap quickly is almost as important as lateral control, particularly under forced-landing conditions.

In a number of practise forced landings, it has been found that it becomes necessary to alternately lower and raise the flaps to compensate for errors in judgment of gliding angle.

The importance of this can hardly be appreciated until one has attempted a forced landing under several varying wind conditions. For instance, when approaching a landing field under forced conditions, the flap is lowered and half way down in the glide it is discovered that the wind is blowing quite rapidly and the plane will not make the field, it is extremely desirable to be able to wind the flaps up very quickly, pick up speed, and extend the gliding angle until it is assured that the field can be made with safety.

By the time this decision has been reached, the airplane in most cases is at a very low altitude right over the edge of the field, and therefore the flap must be brought into action again very rapidly. It can be seen that a flap requiring a high operating force, necessitating too many turns of the handle, is quite impractical for anything other than landings on normal airdromes with full control of the engine and where there is ample time, and such a flap would be actually dangerous under forced-landing conditions.

Many engineers have asked about the spinning characteristics of Zap flaps, and in a recent controversy in one of the international aviation magazines a correspondent has claimed that the split flap should have very undesirable spinning characteristics. There are two things to offset this impression: First, the relation between drag and the slope of the lift curve is very favorable; and second, in the B/J company's XOJ biplane on which flaps were installed, it was absolutely impossible to spin the airplane either with power on or off, even when the center of gravity location was 4 per cent farther back than the plane was designed for. In a normal stall there is no particular tendency for the plane to rotate in either direction, and the nose merely drops forward until the plane has picked up speed.

In this connection it is interesting to compare the difference between the acute stalling of a Zap-equipped airplane of 12 or 13 lb wing loading and that of an airplane of straight airfoil section with the same wing loading. When the latter type is acutely stalled, where the landing speed is around 55 to 60 mph, there is a resultant dive from which the pilot does not attempt to recover until the airplane has reached a speed of at least 70 to 80 mph. Because of the attitude of the plane in the downward plunge and the relatively horizontal attitude of the lift vector whose vertical component necessary to overcome the force of gravity is relatively small, the airplane must be allowed to traverse a considerable vertical distance in order that the lift vector may be acting efficiently in overcoming gravity. Any attempt to pull the plane out previous to this time is more or less injudicious, because the inertia of the plane at the speed of 70 to 80 mph is so great as to cause a mushing action, with a resultant angle of attack that might again put the airplane into a spin. Those who have seen the training that went on during the war in JN-4's realize exactly what this means, because time and again students have been seen to spin for several hundred feet, stop the rotation, enter a dive, and immediately go into a spin from the dive in the opposite direction. With a lightly loaded airplane, say of 5 to 6 lb per sq ft, which means a flying speed of approximately 40 mph, in a similar stall, the airplane can be pulled out of its dive at 20 to 30 mph less speed than under the first condition, simply because the inertia is reduced as the difference between the square of two velocities, and being so much less the airplane can be brought to a level flying attitude with a considerable reduction in vertical descent. Because a flapped airplane also flies at a reduced rate, the inertia forces are consequently less, and therefore a stall is less dangerous when close to the ground, as it acts similar to the light-wing-loaded type.

There is a mass of additional data of a specific nature that might have been included, and the author will be very glad to furnish this to those engineers who are further interested in the application of Zap flaps and ailerons to their particular designs.