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EFFECT OF PERIODIC CHANGES OF ANGLE OF ATTACK
ON BEHAVIOR OF AIRFOILS.

By R. Katzmayr.

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NOTICE

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EFFECT OF PERIODIC CHANGES OF ANGLE OF ATTACK ON BEHAVIOR OF AIRFOILS.*

By R. Katzmayr.

Both from theoretical considerations and the observation of bird flight, we have learned that soaring flight is possible only when an airfoil can draw energy from the surrounding air; also, that this can be best accomplished in gusty weather. The correctness of the above statement was, moreover, verified by the Rhone soaring flights of man-carrying, engineless airplanes in the autumn of 1921. Only qualitative tests had hitherto been made on the effect of periodic changes of the angle of attack of resisting bodies. These experiments also confirm the claim to a considerable reduction in the drag with only a slight influence on the lift.

In May, 1921, the writer began a series of experiments, which, although still far from completion, has already given quantitative results on the effect of periodic changes in the direction of the relative air flow against airfoils. The experiments, which were performed in the aerodynamic laboratory of the Vienna Technical High School, may be divided into two series. The first series embraces all the experiments in which the angle of attack of the wing model was changed by causing the latter to oscillate about an axis parallel to the span and at right angles to the air flow. The second series embraces all the experiments in which the direction of the air flow itself

* From "Zeitschrift für Flugtechnik und Motorluftschiffahrt," March 31, pp. 80-82, and April 13, 1922, pp. 95-101.

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was periodically changed.

The results of the first series of experiments will be given first. A knowledge of the general plan of the Vienna aerodynamic laboratory is here assumed.* I will simply mention that the direction of the air flow is vertically downward and that the experiment chamber is freely accessible, the same as in the Göttingen laboratory.

It is evident that the strong oscillations, necessarily occurring in these experiments, could not be sufficiently damped by the ordinary devices. For this purpose, there was attached to the balance a (for determining the lift) (Fig. 1) an extension b, from the free end of which hung a plate d, immersed in a vessel of oil c. The float-balance e (for measuring the drag) was likewise damped by a plate g, immersed in a vessel of oil and connected with the float-balance by means of the wire h. The lift and drag were measured separately, since the manner of attaching the drive for oscillating the model did not allow the simultaneous measuring of both values. The model was supported in the air stream by means of two sheet steel pieces of the shape shown in Fig. 2. The pieces m penetrate the model at two points, where there are pivots n, about which the model can be readily turned with reference to the steel pieces. Contrary to the usual method of suspending the wing model in the air stream, the pieces m are attached to the float-balance e by means of the vertical wires i and to the balance a by

* Von Doblhoff, ZFM, 1914, Nos. 7 and 8: "Das Aeromechanische Laboratorium der Lehrkanzel für Luftschiffahrt und Automobilwesen an der k.k. Technischen Hochschule in Wien."

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means of the horizontal wires o and p. The model q could turn freely about the pivots n, without affecting the balances. In measuring the lift, the wing model q was oscillated by means of the eccentric drive v_1, and the wires r and s (Fig. 1), which were attached to a cross-piece t, rigidly connected with the model, and to the double-armed lever u_1. The latter oscillated about the axis w_1. The eccentric drive v_1 received its power from the electric motor x_1. While determining the lift the drag balance was held stationary. Since r and s were exactly perpendicular to o and p, the readings of balance a were not affected. In determining the drag, the model q was oscillated by the horizontal rod y_2, which was connected with the vertical lever z_2. The latter oscillates about the pivot w_2, thereby oscillating the model q about the axis n. The rod z_2 was oscillated by the lever u_2, which was driven by the electric motor x_2 and the eccentric v_2. Since the length of the lever arm z_2 equalled the distance from the leading edge of the wing to its axis of rotation n and the rod y_2 was always perpendicular to the direction of the wires i, the determination of the drag was not affected by the oscillation of the model.

The experiments were performed with the Göttingen wing section G189, shown in Fig. 3a. Its dimensions were 720 x 120 mm. It was subjected to three wind pressures of p = 5, 10 and 20 mm of water and also to three different oscillation speeds of the model (20, 30 and 50 complete oscillations per minute) at differ-

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ent oscillation angles β (Fig. 4). The latter were set at $\pm 9^\circ$, $\pm 12^\circ$, and $\pm 15^\circ$, while the mean angle of attack α was given the values -6°, -3°, 0°, 3° and 6°.

The results are shown in Table 1 and Fig. 5. At the outset it must be stated that the results, at least within the allowable error limits, were independent of the oscillation speed of the model. The influence of the wind pressure on the results was normal, i.e., increasing pressure gave more favorable values of L/D. In every instance, the oscillation of the airfoil, in an air flow of uniform velocity and direction, produced a decidedly unfavorable effect on both lift and drag. The latter increases with the amplitude of the oscillation angle $\pm\beta$. The position of the individual points of the diagram for different oscillation angles is worthy of note. They lie, with considerable accuracy, on straight lines intersecting at a point which might be termed the "pole". The practical significance of this fact is that, for a given, rather large oscillation angle β (a variation of the zero angle α, about which the oscillations occur), there is no change in the magnitude of the air force. Hence, the airfoil works like any ordinary resisting body of simple definite lift and drag. In any case, it is of practical significance that, with a wind blowing in a constant direction, no improvement of the aerodynamic properties of an airfoil can be obtained by causing it to oscillate about an axis n lying within the perimeter and parallel to the edge of the airfoil.

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The question arose as to whether these results would be changed; if, instead of turning periodically about the axis n, the oscillations were parallel to the chord of the airfoil. In this event, there would be no change in the angle of attack, but rather a change in the aerodynamically effective starting angle, corresponding to the flapping of a bird's wings. For these experiments, the model was suspended in the air stream the same as for an ordinary experiment. The balance a was, however, placed on a slide, so that it could be shoved back and forth on a horizontal base, the motion being transmitted to the model by means of the retaining wire. In fact, the leading edge of the airfoil made an insignificant motion parallel to the direction of flow, caused by the oscillation of the model about the upper suspension point of the wires i (Fig. 1). The amplitude of these oscillations was only 0.8 mm and may therefore be disregarded. The amplitude of the oscillations perpendicular to the direction of flow was 100 mm. The experiment was first tried with the model G189. The oscillation numbers per minute were 11.5 and 28.5. The results, given in Fig. 6, show, in both cases, a change for the worse in the aerodynamic constants of the airfoil, in comparison with those for a motionless model in a uniformly flowing air stream. The change for the worse is greater for a larger number of oscillations per minute. In both cases, there is a marked increase in the drag, while the lift is only slightly diminished. The airfoil G413 (Fig. 3b) was also tried under like conditions, the number of oscillations per minute being

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30 and 37.5. From Fig. 7, which gives the results, we see that this airfoil was also affected unfavorably by parallel oscillations in a uniformly flowing air stream.

As already mentioned, the second series embraced all those experiments in which the model remained stationary in the air stream, while the direction of the air flow itself was subjected to periodic oscillations. The device, which was installed at the mouth of the outlet cone is shown in Fig. 8. It consists of four streamlined bodies: 1, 2, 3, and 4, of the shape and dimensions shown in Fig. 9. They were attached by flexible straps on the end toward the outlet cone. The spacings between them were 120 mm and their trailing edges were 600 mm from the leading edge of the airfoil at q. The arrangement was such that the model did not stand directly in line with either of the guiding bodies. To the trailing edges of the guiding bodies 1-4 the rods 6-9 were respectively attached in such manner that all the guides moved in unison. Rod 7 was specially long and was attached to the eccentric wheel v_3 driven by the motor x_3. The guiding bodies 1-4 could be made of other lengths by attaching the connecting rod at other points on rod 7. Since the air speed could not be measured with the ordinary laboratory equipment, a simple Pitot tube was attached to rod 7, just above the airfoil, so that its open end came between guides 2 and 3. A rubber tube connected the Pitot tube to the manometer 11 (Fig. 8). The manner of suspension of the airfoil and the reinforced damping device were the same as in the first series of experiments.

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The first task was to determine the effect of the oscillating guides 1-4 on the air stream. By means of woolen threads held in the air stream, it was found that although the guides embraced only the middle portion of the air stream, the latter was very uniformly deflected throughout its whole width. The guides could be turned through an angle up to $\beta_1 = 26^\circ$ without the air flow becoming noticeably separated from their surfaces. There occurred, however, a strong disturbance of the air flow. The following experiments were therefore only carried to $\beta = \pm 24^\circ$. When the guides 1-4 oscillated, all the threads swung synchronously, though their maximum deflection was somewhat less than that of the guides. In the following tables there are accordingly given both the maximum deflections β_1 of the guides and β of the threads. The latter was found by hanging in the air stream a finely drawn glass tube, which, on account of its light weight assumed with sufficient accuracy the direction of the threads. Also errors due to gravity cannot have been very large. The greatest deflections of this glass indicator were observed with a cathetometer and read on a curved scale. Since both positive and negative angular deviations were read and compared, it may be assumed that no great absolute errors could have been made in the determination of the direction of the air flow. At any rate, reliable comparative values between the individual series of measurements were obtained. The glass tube, used as an indicator, was suspended in the air stream a little above the leading edge and beyond the influence of the model.

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As already mentioned, the air pressure was measured with a Pitot tube. Its readings were compared with a control tube and a second micromanometer and both the reliability of this method of measuring and the uniformity of the velocity of the different portions of the air stream were verified. It is obvious that the oscillations of the guides must produce pulsations in the air stream. Thus far it has not been possible to determine these quantitatively by simple means. They could not, however, have been very great, since both manometers varied but slightly during the experiment.

The best proof of the reliability of the guiding device probably consisted in the fact that, through a gradual turning of the guides 1-4 with a stationary model, the normal and tangential force lines of the wing model could be directly obtained, since, in the above manner, the change in the angle of attack was effected by changing the direction of the air flow and the air force components perpendicular and parallel to the wing chord could be weighed directly by both balances. A comparison of the normal-tangential (N & T) line, thus obtained, with the line obtained from the lift-drag line gives a noteworthy agreement of both lines, as may be seen in Figs. 10-12 for the three airfoils shown in Figs. 3a, 3b, and 3c. Therein the encircled points indicate the values obtained by deduction from the lift-drag line and the points marked with exes indicate the values obtained by direct weighing.

The models G189 and G413 and also the airfoil LA109 (Fig. 3c)

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were employed in the experiments.* The latter had the regular dimensions, 900 x 150 mm, employed in the Vienna Institute. Along with two thick wing sections, of different dimensions but the same aspect ratio, a thin one was accordingly also tested. All the tests were made with a pressure of 20 mm of water. Each model was subjected to six different degrees of change in the direction of the air blast and also to at least two different oscillation speeds of the air stream. The angle of attack of the model was changed 3 degrees at a time from 0 to 15° (or 18°). Since the oscillations of the guiding mechanism took place symmetrically about the zero direction determined by the direction of the supporting wires i, the lift and drag values could be directly determined by weighing . Each model was subjected to the blast with the guiding mechanism at rest and also with it removed. These experiments produced the known phenomenon of an improvement in the aerodynamic characteristics of a wing model with increasing turbulence of the air stream, as combined in Figs. 13-15.

Table 2 and Fig. 16 throw light on the behavior of section G189 (Fig. 3a), while table 3 and Fig. 17 show the behavior of section G413 (Fig. 3b) and table 4 and Fig. 18 show the behavior of wing section LA109 (Fig. 3c) in an oscillating air stream. For convenient comparison the lift-drag line of the given section is included in each figure.

Consideration of the results shows first that the effect of

* The wing section G413 is taken from the First Report of the Göttingen Aerodynamic Laboratory, p.78. Wing section LA109 is copied from a wing section taken from the lower wing of an Anatra biplane.

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an air stream with periodic changes in direction is quite different from that of its mechanical analogon, an oscillating model in an air stream flowing in a constant direction. All the tested wing sections show in common a considerable reduction of the drag, which, however, is combined with a reduction in the lift. The latter is not sufficient, however, at least for the small angle of attack α, to impair the lift-drag ratios ϵ. With the thick wing sections, a negative drag with a positive lift could be repeatedly measured, corresponding therefore to forward ascending flight. The tested models all show further that with increasing magnitude of the changes in direction of the air stream, the aerodynamic constants of the model improve in the above direction, although this phenomenon seems to have an upper limit, since e.g. the section G189, beginning at an oscillation angle of $\beta \cong \pm 9^{\circ}$; section G413, beginning at $\beta \cong \pm 11^{\circ}$; and section LA109, beginning at $\beta \cong \pm 12^{\circ}$, show a new increase of the drag with a further reduction of the lift. Regarding the influence of the number of oscillations of the air stream per minute, it could be established that this is of little importance, as appears especially from table 5, referring to section G189, which was subjected successively to 27.3, 43, 100, and 106 oscillations of the air stream per minute. On the other hand, the experimental results of sections G 413 and LA 109 show that, with a smaller number of oscillations, a somewhat greater lift, but also a greater drag could be observed. In Figures 16 - 18, the lift-drag lines were introduced only as mean values of the experimental results for different oscillation numbers. It is worth noting that 112 the above-mentioned phenomena occurred at a relatively small angle of deflection of the direction of flow and even at 30 oscillations per minute. Hence a period of two seconds for a complete oscillation sufficed to accomplish considerable improvement in the aerodynamic properties of a wing section.

Although the experiments of series 1 showed that no practical use was attainable by periodically changing the aerodynamically effective angle of attack of a wing in a constant air stream, "combined" oscillation experiments were nevertheless undertaken with the model G413. Hereby the wing model not only oscillated about the angles of attack $\alpha_o = 0^\circ$, 6° and -6° with $\pm 5^\circ$ amplitude, but the air stream also changed synchronously its direction of flow about the zero position $\beta_o = 0^\circ$ between the maximum values $\beta \cong \pm 5^\circ$ (oscillation of guiding mechanism $\beta_1 = \pm 12^\circ$). The eccentric wheel drove not only the guiding mechanism, but also (Fig. 1) the lever w_2 with the lever z_2 and the rod y_2. The oscillations of the model and of the air stream were synchronous though not of like phase, but showed in consequence of the shortening of the rod, the course plotted in Fig. 19 of the changing of the aerodynamic angle of attack α_i. It may be deduced from the figure that the angular deflections of the model and air stream are constantly combined in such manner (though not harmonically), that one oscillation takes place for every wave trough and crest. The drag was simply measured at $p = 20$ mm of water. Table 6 shows that the influence of the oscillating wing model on the final result is also unfavorable. The strengthening of the changes of α_i through synchronous oscillations of the wing itself are consequently not of equal aerodynamic value with a greater change in the direction of the air stream.

The experiments are still far from being finished. At first no stability investigations were undertaken and the experimental methods are yet to be improved. It is however already established that the effect of flowing air, whose direction is undergoing constant periodical changes, is extraordinarily favorable on airfoils. The results show further that wing sections which exhibit favorable characteristics in a constant air flow, work still better in an oscillating current, and also that wing sections with high resistances are better in practice. Periodic oscillations, or parallel motions of the wings in uniformly flowing or even in an oscillating air stream, always considerably impair the aerodynamic properties.

Translated by National Advisory Committee for Aeronautics.

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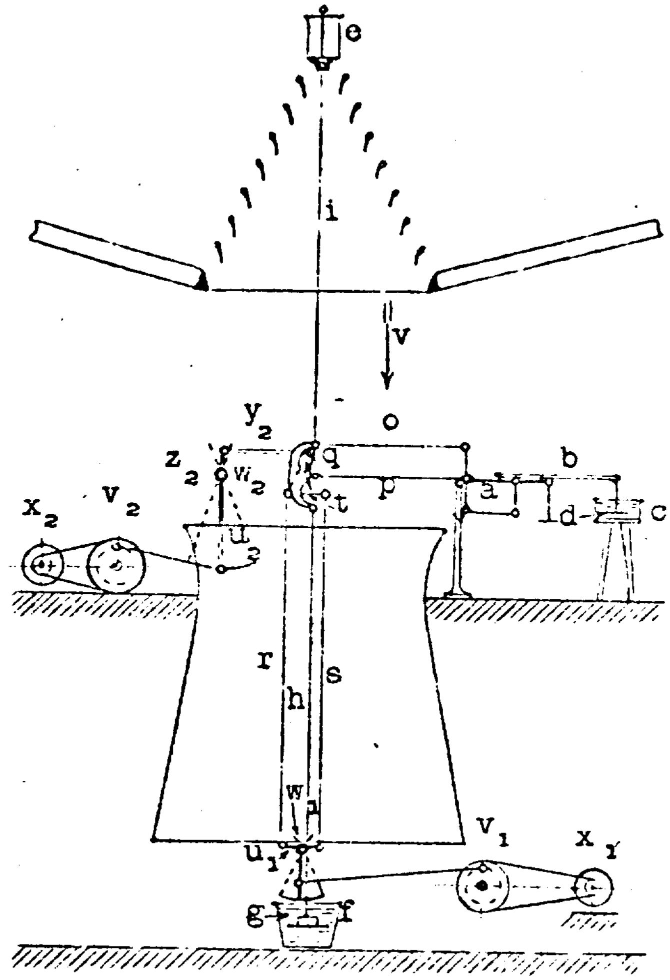


Fig. 1 - Sectional diagram of Laboratory.

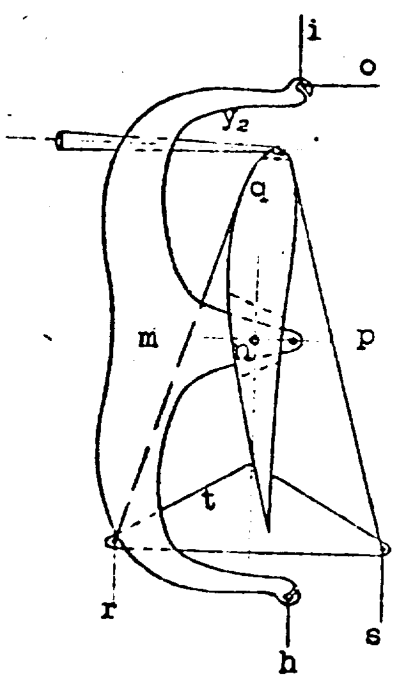
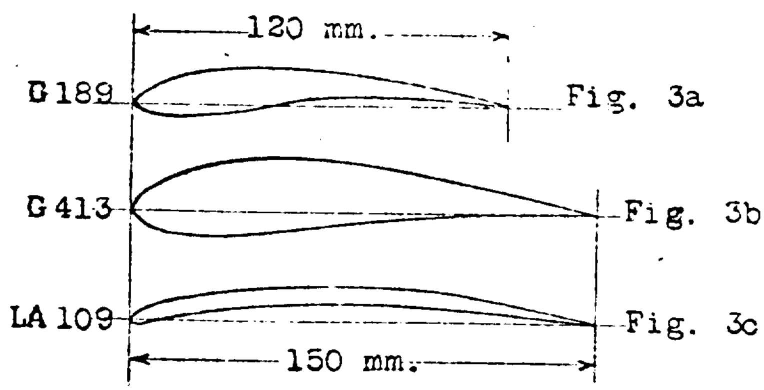


Fig.2 - Method of supporting model.



Airfoils used in test.

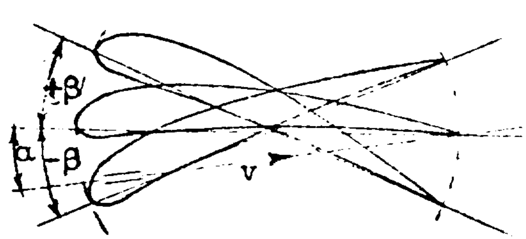


Fig. 4 - Oscillation angles.

Fig. 1 - 2 -3a -3b- 3c - 4.

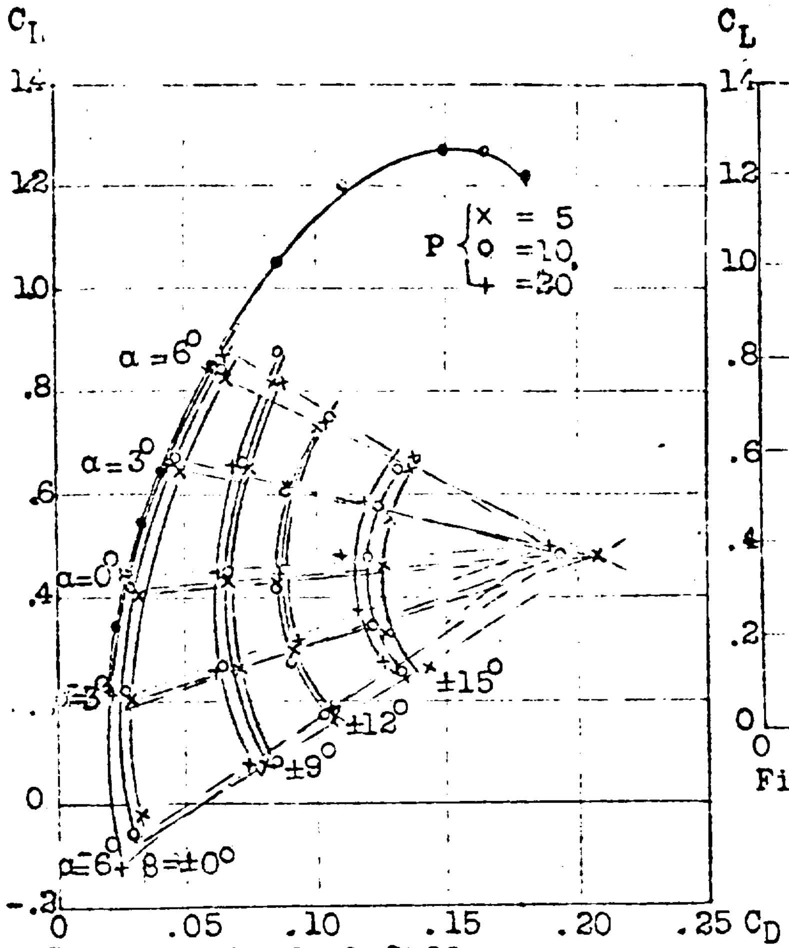


Fig. 5 - Airfoil G189.
Angle of attack = α
Angle of oscillation = β
Wind pressure, mm of water = p.

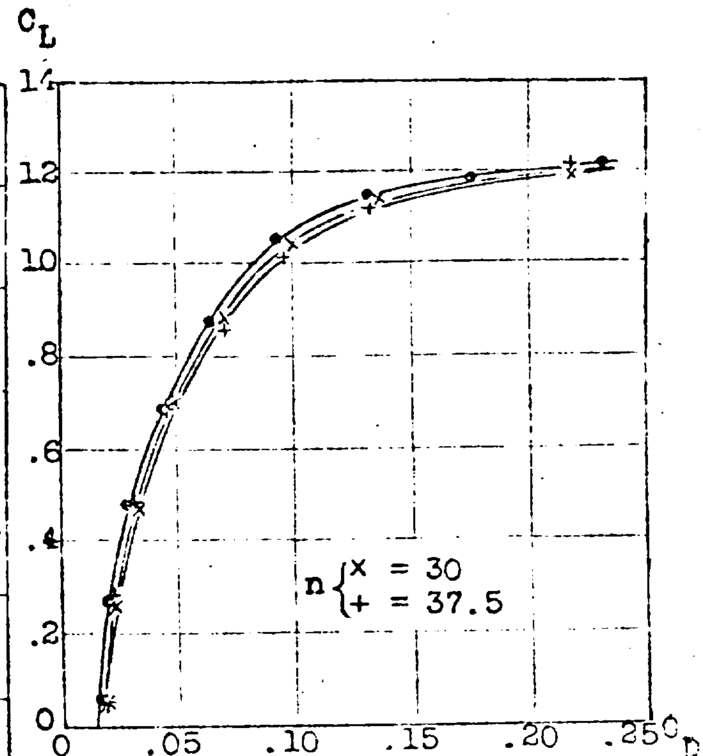


Fig. 7- Airfoil G413. Oscillations per minute = n.

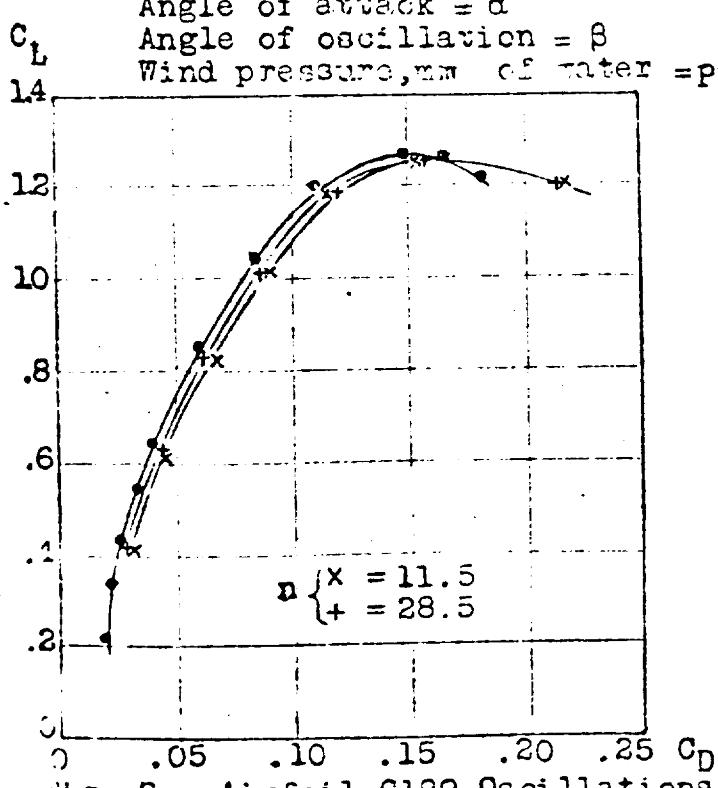


Fig. 6 - Airfoil G189. Oscillations per minute = n.

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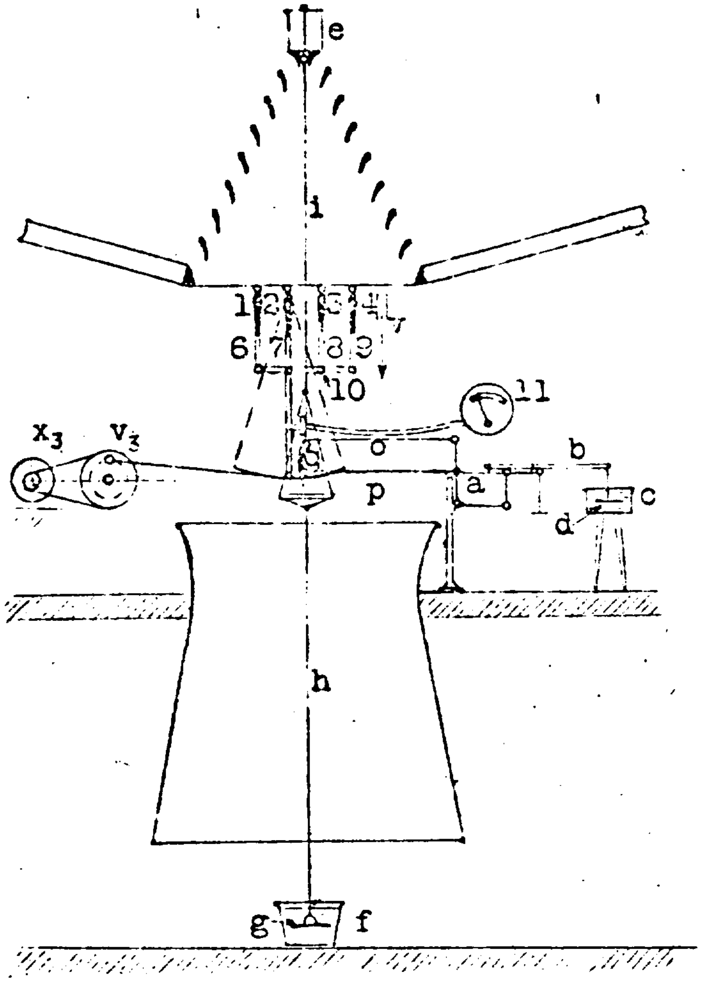

Fig.8 - Sectional diagram of laboratory.

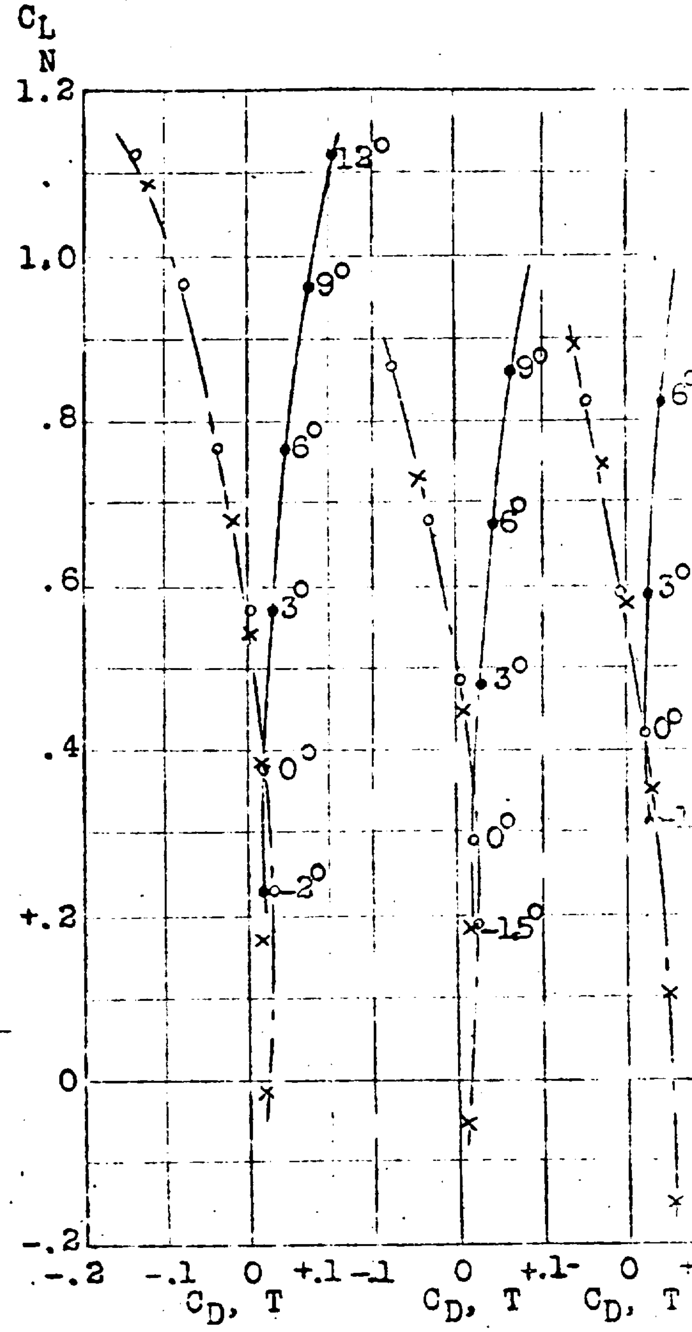

Fig.10 G189 Fig.11 G413 Fig.12 LA109

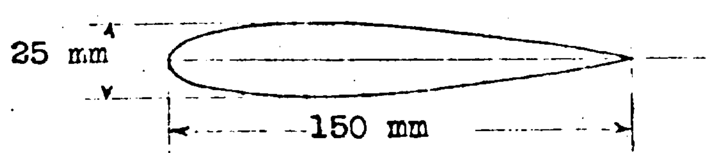

Fig. 9.

16a

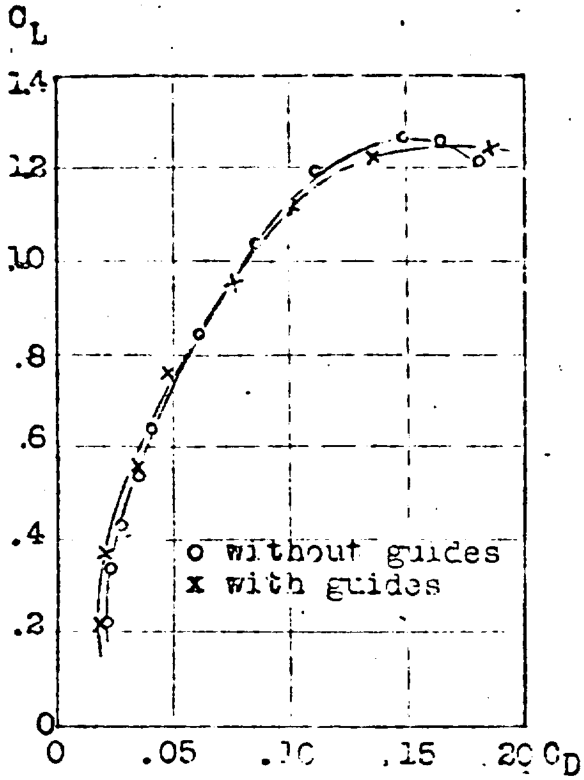

Fig.13 - G189

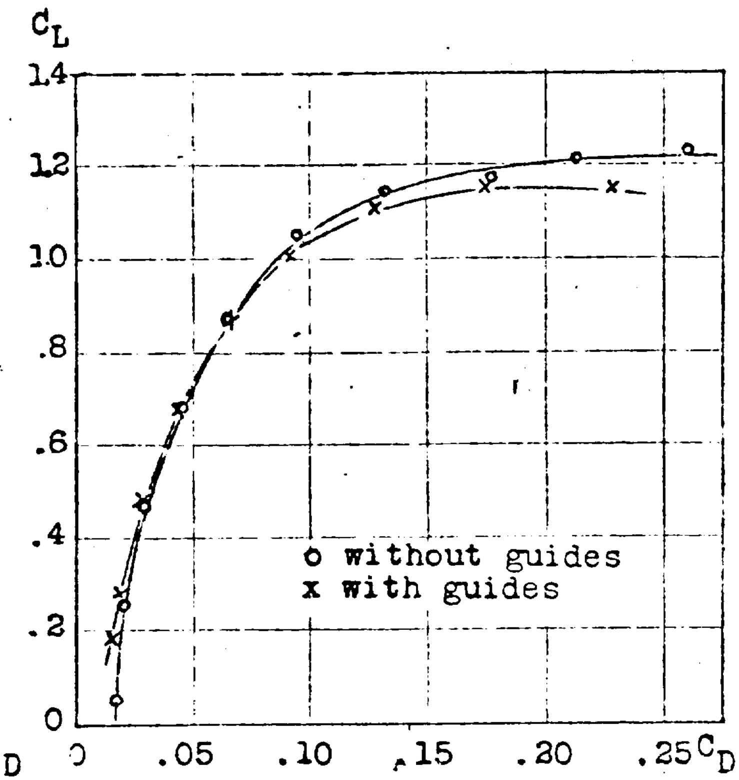

Fig.14 - G413

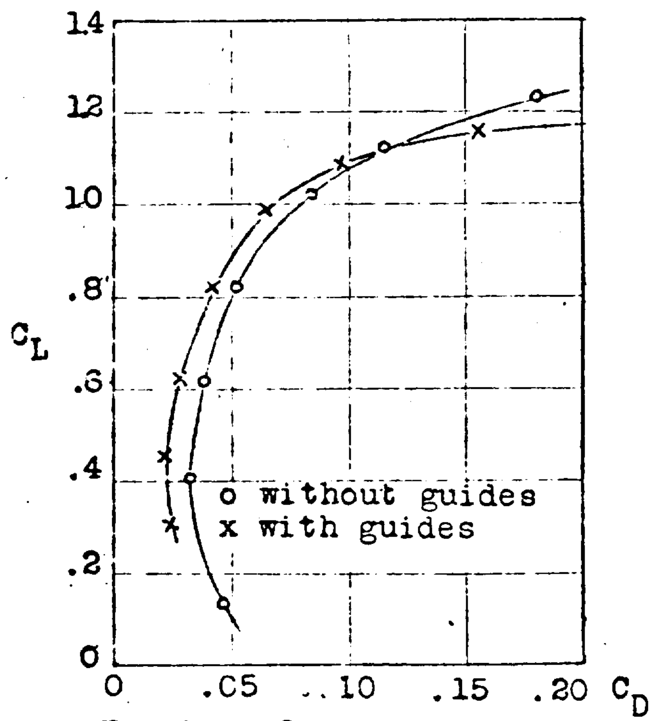

Fig.15 - LA109.

Figs.13-14-15.

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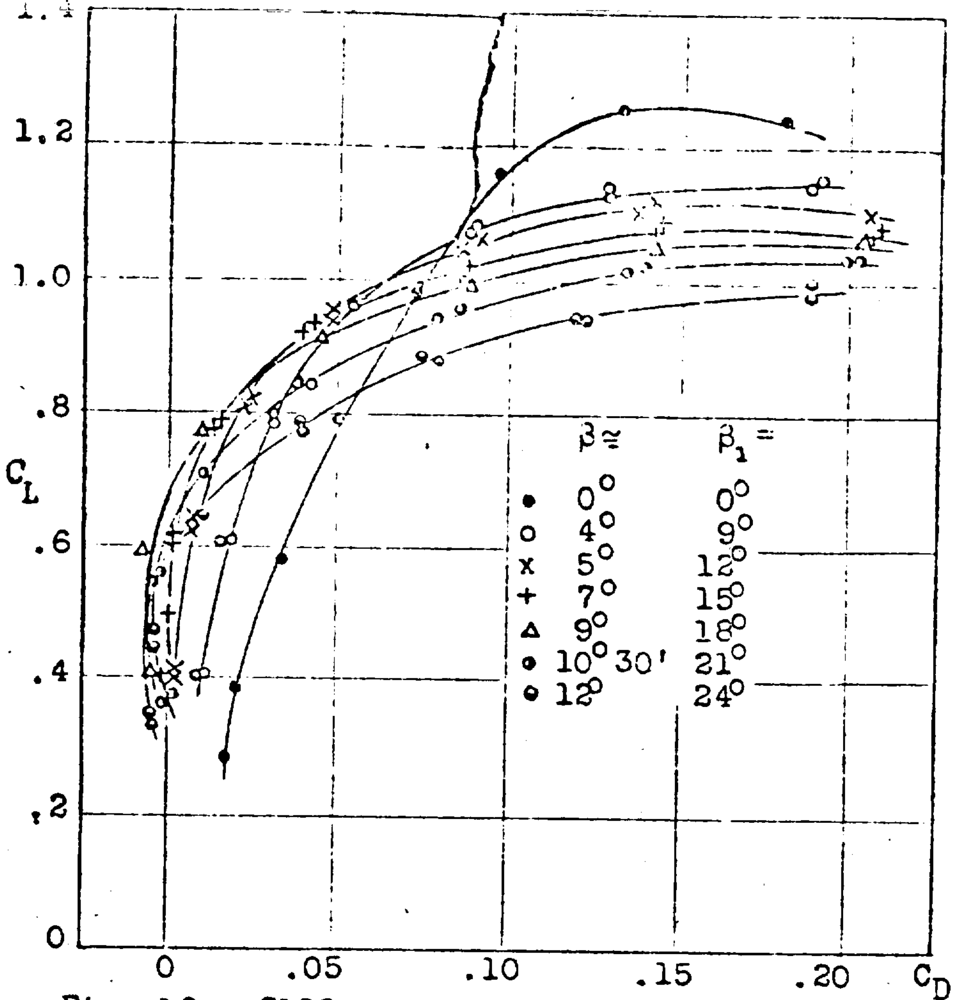

Fig. 16 - G189.

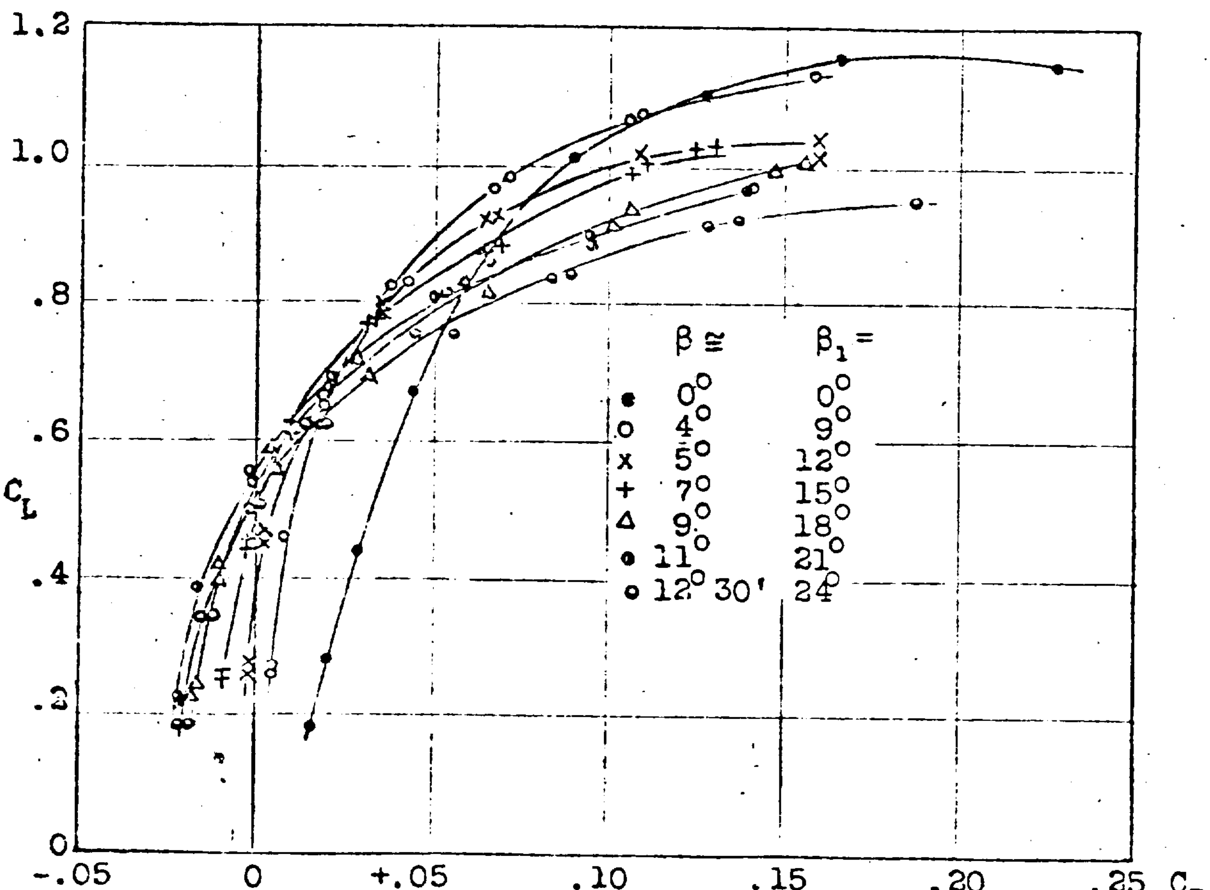

Fig. 17 - G413

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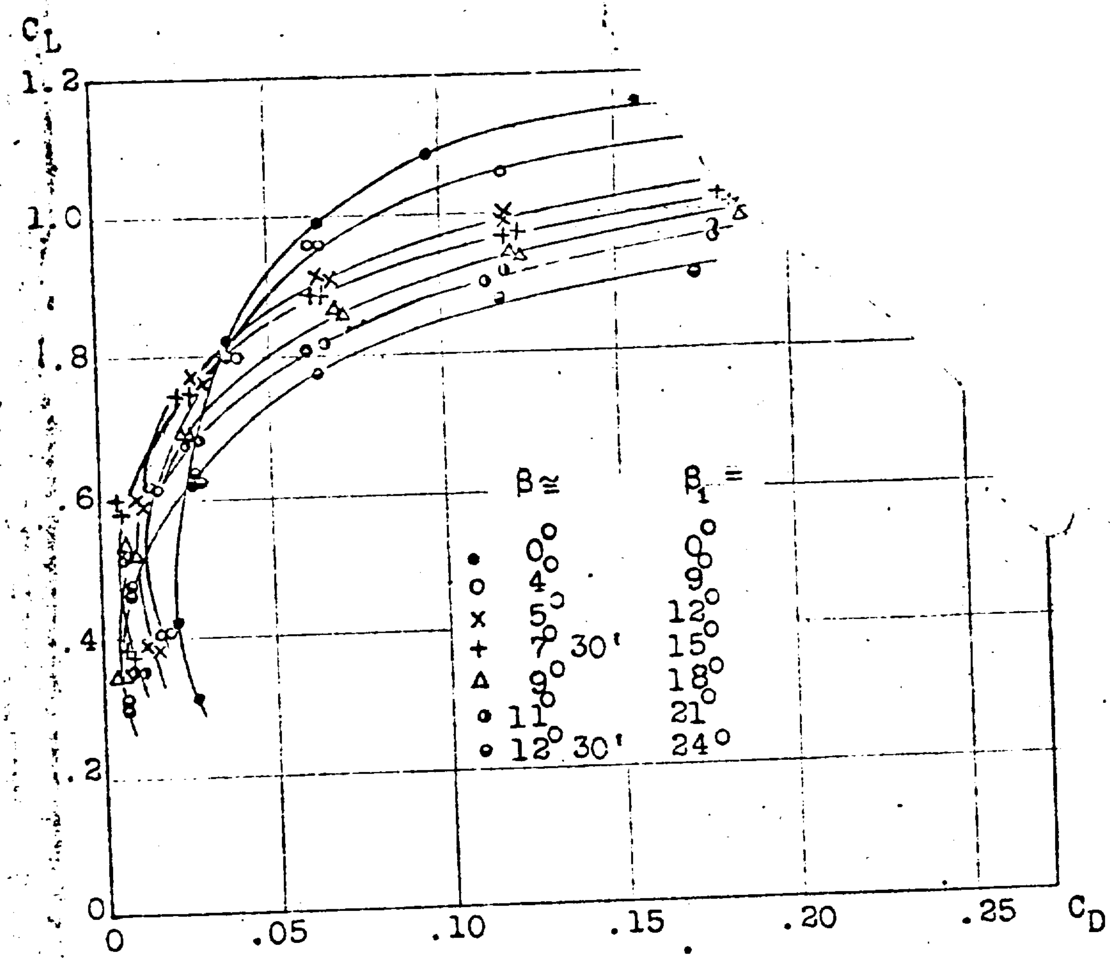

Fig. 18 - LA109

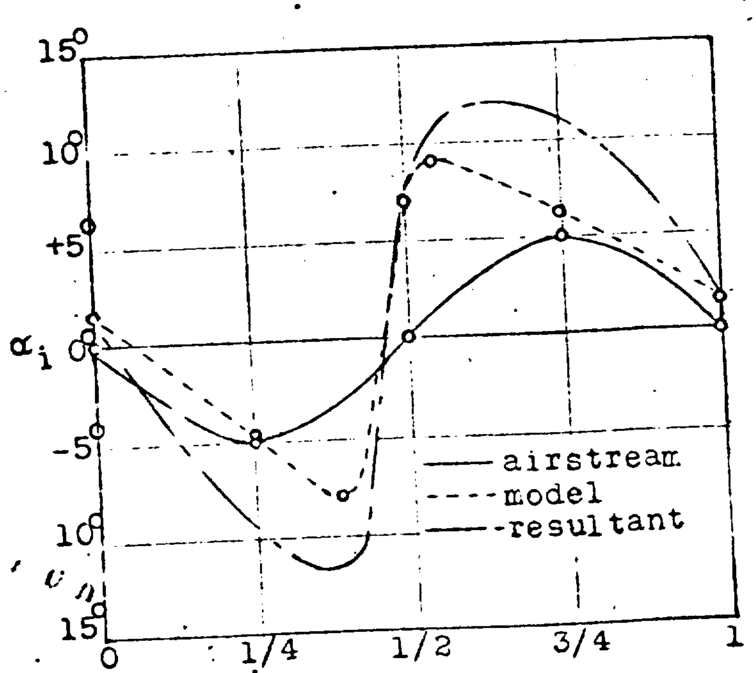

Fig. 19

Figs. 18 & 19.