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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TECHNICAL MEMORANDUM

No. 1104

THE INFLUENCE OF THE JET OF A PROPULSION UNIT
ON NEARBY WINGS

By H. Falk

Reprint

Der Einfluss eines Triebwerkstrahles auf einen
in Nahe befindlichen Flugel

Untersuchungen und Mitteilungen Nr. 3200

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ON NEARBY WINGS*

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ABSTRACT: The present investigation was intended to ascertain how far a tail unit is subject to disturbances by the jet of a propulsion unit. The parameters upon which this disturbing influence depends, and the values it reaches, had to be determined.

OUTLINE: I. Statement of the problem
II. Test procedure
III. Results of measurement
IV. Approximate representation of the results
V. Summary
VI. Bibliography

I. STATEMENT OF THE PROBLEM

Additional forces are probably exerted upon a supporting wing, for instance a tail unit, if it is located behind a propulsion unit with an emitted jet. These forces must be traced back to the presence of the jet. Figure 1 represents schematically such an arrangement. Forces of this kind may disturb the stability of flight. A basic test will help us to ascertain the influential parameters and to determine the magnitude of the forces.

*"Der Einfluss eines Triebwerkstrahles auf einen in Nähe befindlichen Flügel," Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen Nr. 3200.

Essentially, there are two effects of decisive importance. The first effect is based on potential theory and was already treated by P. Ruden (1) for the case of a plane wing in the proximity of a plane jet (or of a region with slow flow). The pressure distribution on the wing is disturbed by the uneven distribution of the total pressure; additional forces result. Therefore, the thickness of the wing will be of foremost importance in this effect. (Other quantities of influence will be discussed later.) An infinitely thin wing at zero angle of attack will not experience any forces.

The second effect is founded on the intermixing of the jet with the surrounding flow not based on potential theory. The turbulent spreading causes the appearance of a velocity component directed toward the jet in certain regions. These conditions were discussed in numerous reports since W. Tollmien (2); recently they were also treated numerically for the core of the rotationally symmetrical jet by O. Pabst (3) and H. Szablewski (4).

The following parameters are probably the most influential ones: the propulsion jet, which for this investigation is assumed to be unheated, will be characterized by its velocity v_A in the exit of the propulsion unit. v_A differs from the undisturbed oncoming flow v_0 . Apart from the ratio v_A/v_0 of the two velocities the difference $v_A - v_0$ will also play an important part. (Compare (5).)

The position of the wing in relation to the jet will be most important for the interference effect upon the wing; therefore, in our case of the rotationally symmetrical jet the coordinates x and z of for instance the leading edge in the coordinate system characterized in figure 1 will be of main importance. The wing span and the coordinate of the wing in the direction of the span are not considered in our investigation since we assume the span in both directions to be large compared with the jet diameter. On the wing itself its thickness d and its chord l will be of influence, the ratio d/l no less than the ratio d/d_A (thickness of the wing-jet diameter). The profile form, which will also be of influence, was changed but slightly in our experiments since existing wings are to be used for the measurements; we limited ourselves to symmetrical profiles. Both the

propulsion unit and the wing may be inclined toward the direction of the oncoming flow and so form an angle with respect to each other also. Investigations were made only for conditions of symmetry so as to hold down the extent of the measurements; moreover, the wing was always adjusted in the direction of the undisturbed oncoming flow so that without interference effect the lift was zero. In most of the experiments the jet left the propulsion unit in the direction of the oncoming flow. Only in a few cases the axis of the propulsion unit was inclined at an angle α toward the oncoming flow.

II. TEST PROCEDURE

Figure 2 gives a schematic representation of the experimental arrangement. A model propulsion unit with a built-in blower which had been used before by H. Baerle (6) was suspended in the open jet of wind tunnel III ($1.0 \times 1.5\text{m}$). A wing was supported in the customary manner by the three-component balance behind the propulsion unit in the center of the jet; however, only the lift was measured. The relative position of propulsion unit and wing was changed by fixing the wing and shifting the propulsion unit upward and in the direction of the opening of the nozzle. All distances were measured in units of d_A (d_A diameter of the exit opening of the propulsion unit = 70mm). In the x-direction the distances $x/d_A = 1, 2, 4, 6, 8$ and in z-direction the region $0 \leq z/d_A \leq 4$ were measured. Seven different ratios v_A/v_0 , namely $v_A/v_0 = 0.77, 1.85, 2.05, 2.5, 3.0,$ and 4.0 are apportioned to each point behind the propulsion unit. The first value corresponds to the model propulsion unit at rest. Additional measurements were taken for static conditions. The measurement does not exactly conform to the value $v_A/v_0 = \infty$ since the whole wind-tunnel jet had been put into a slight motion. Generally, the jet velocity v_A was kept constant at 90 m/s; v_0 was changed accordingly.

Three different wings with symmetrical profiles and the following characteristics were at our disposal for measurement:

	l (mm)	Λ	d/l	d/d_A	l/d_A
Wing I	300	2.0	0.16	0.69	4.3
Wing II	175	3.4	0.10	0.25	2.5
Wing III	125	4.0	0.09	0.16	1.5

Wing I had a modified Joukowski profile with increased angle of the trailing edge and straight sides; wings II and III had the customary NACA drop shape.

The angles of attack of the propulsion unit $\alpha = 3^\circ$ and $\alpha = 6^\circ$ on wing II were measured in the same arrangement. Since at $\alpha = 0$ the flow is no longer symmetrical to the axis of the propulsion unit, negative z -values also had to be measured simultaneously. In order to keep out of the disturbance range of the suspension of the propulsion unit the latter was tilted in opposite direction at the same angle of attack; therefore, the wing always remains in the region underneath the propulsion unit.

III. RESULTS OF MEASUREMENTS

The results are represented graphically in the form of a lift coefficient c_a^* in dependency on z/d_A for various x/d_A and v_A/v_0 in figures 3, 4, and 5. The lift is referred to the stagnation pressure of the free stream $\rho v_0^2/2$ and to the area $d_A \times l$. The jet diameter d_A rather than the span was inserted as the length in order to keep the result independent of the span. Figure 3 includes all the values for the wing I with an angle of attack $\alpha = 0^\circ$. The course of the curve shows a distinct maximum and consequently an asymptotic falling off toward zero with increasing z -values. The rise from zero toward the maximum values is steep compared with the decline. The curves for negative values are to be inverted with respect to the zero point; this process also inverts the sign.

The extreme value of c_a^* lies for all x -values near the jet boundary; with increasing x it moves slightly outwards. With v_A/v_0 diminishing the maximum value c_a^* also decreases. The lateral force which is directed toward the jet for $v_A/v_0 > 1$ should have the opposite direction for $v_A/v_0 < 1$. This circumstance is not always brought out clearly by the measurement, due probably to inaccuracies in measuring.

Generally speaking, the same conditions prevail for wings II and III as for wing I as shown in figures 4 and 5. The course of the curve retains the same form; nor does the local position of the maximum change. The maxima for the three wings differ in size only.

Figure 6 shows the results of measurements for static conditions. Here the lift coefficients c_a^{**} are referred to $\rho v_A^2/2$. The graphs show the course for various x -values.

The measurements for the wing with the propulsion unit at an inclination are compiled in figures 7, 8, and 9. The curves are not symmetrical with regard to the zero point. A range of direct influence must be distinguished from a region of interference. If the jet is pointed at the wing there results in our arrangement a negative lift of the wing. In the main, the same course appears for the positive c_a^* values as indicated for $\alpha = 0^\circ$. The negative c_a^* values attain maximum values which differ considerably from the positive ones. The slope toward zero is much greater for the negative values than it was in the positive section. With increasing x the point of transition through the zero line approaches higher z -values.

A number of corrections had to be introduced in evaluating the results of measurement; these corrections shall be treated subsequently. Each wing showed a small lift even without propulsion jet; this lift is caused by the one-sided suspension of the propulsion unit. Another effect of disturbance is to be traced back to the position of the propulsion unit with respect to the opening of the nozzle. A normal formation of the open-jet is increasingly impeded the more the propulsion unit

is shifted from the center of the jet toward the boundary. The greatest disturbance is to be expected for the values $x/d_A = 8$ and relatively high values of z/d_A because in this case the propulsion unit is suspended quite near the opening of the nozzle and causes the maximum deflection of the jet. Naturally, the deformation of the jet also depends upon the force of the propulsion jet and the inclination of the propulsion unit.

The simplest method to eliminate the disturbances indicated above is to extend the measurement to z/d_A values of such magnitude as to guarantee the nonappearance of the described effect. Thus one determines the asymptotes which can then be used as zero line. This mode of procedure worked reliably in every case.

The method was rendered more difficult by measuring the negative z values (as indicated above) in a way different from the one used in measuring the positive values; it was aimed at reducing the disturbance caused by the suspension of the propulsion unit. It may be the case that the curves do not join at $z = 0$. A mean value was used in the evaluation.

IV. APPROXIMATE REPRESENTATION OF THE RESULTS

So far the results were discussed as they were obtained for the special arrangements. Now we shall try to find relations which will make it possible to draw conclusions as to any arrangement. To this end the specific conditions have to be eliminated from the results of the experiments.

The definition of the c_a^* value given above contains already certain generalizations. First of all the diameter of the jet d_A was introduced as a reference quantity; hereby the span of the wing was eliminated. The span was for each case tacitly assumed to be so large as to completely cover the region of interference. As a second step the wing chord l was removed by selecting $d_A \times l$ as reference area. The thickness of the wing d and the ratio v_A/v_0 and difference $v_A - v_0$, respectively, were recognized as the most important remaining parameters.

c_a^* was assumed to be proportional to $v_A - v_0$ or $v_A/v_0 - 1$; this proportion is physically plausible for the mixing effect only, not for the potential flow. The remaining quantity

$$\frac{c_a^*}{\frac{v_A}{v_0} - 1} = \frac{A}{\frac{\rho}{2} v_0^2 d_A \times l \left(\frac{v_A}{v_0} - 1 \right)}$$

will be a function of the thickness of the wing d and first of all, based on considerations of potential theory, a function of the ratio d/l . Here also we assumed a linear dependency. Furthermore the ratio of d/d_A (thickness of the wing/diameter of the jet) also will appear; for it is easily conceivable that a thin jet will have less influence than a jet of great extent as compared to the thickness of the wing. We determined the kind of this dependency empirically, using the maximum values c_{am}^* . It becomes obvious that d/d_A also will appear in linear dependency, and that the maxima in all measurements can be reproduced amazingly well by the relation

$$c_{am}^* = 1.18 \left(2 - \frac{d}{d_A} \right) \frac{d}{l} \left(\frac{v_A}{v_0} - 1 \right)$$

as shown in figure 10. Therefore, the value of c_{am}^* increases with v_A/v_0 increases with d/l and decreases with d/d_A . We now tried to represent the whole course of curves over z/d_A also by approximate curves, and, to this end, divided the measured c_a^* values by c_{am}^* .

Figure 10 shows that here also it is possible to draw a uniform curve through all the experimental points. The dispersion is, in the main, unsystematic and the points with the largest dispersion on the average may be attributed to the two small values $v_A/v_0 = 2.05$ and $v_A/v_0 = 1.85$; there the inaccuracies of measurement in this graph are, quite naturally, most noticeable. (These

values are given with crossed out signs.) In this way we obtain the approximate curves represented graphically in figure 11.

These curves, together with the formula for c_{am}^* may be used as a good approximation in the general case. The region of validity will be given by about

$$x/d_A \leq 6$$

$$1 \leq \frac{v_A}{v_0} \leq 4$$

$$d/d_A \leq 1$$

however, the limits of the region were not yet accurately defined. In limiting the region of x/d_A it must be pointed out that the approximation was set up mainly for the case where the potential core is not yet completely reduced so that still the full amount $(v_A - v_0)$ appears as velocity difference. For greater clarity the spreading of the jet is represented graphically in figure 12.

The measurements for static conditions have to be treated specially because of $v_0 = 0$. In this case we divided the measured c_a^* values by the expression

$$f(d, d_A, l) = 1.18 \left(2 - \frac{d}{d_A} \right) \frac{d}{l};$$

it became obvious that the measurements on the three wings approximately coincide again. The resulting approximate curves are indicated in figure 11. Deviations from the course of the curve appear at $x/d_A = 8$ where the potential core has already been reduced to zero (compare (5)).

This evaluation does not include the case of yawed flow since the relations there are not yet sufficiently clarified because of the unknown course of the jet. Further investigations in this respect are intended.

V. SUMMARY

The mutual influence of a jet produced by a propulsion unit and a nearby wing was investigated. The tests concerned mainly three different wings. These wings were suspended in such a manner that they had practically no lift without the influence of the jet; the interference lift was measured. The most important quantities of influence can be determined from the results. They are, apart from the geometrical position of the wing toward the jet, the velocity ratio v_A/v_0 , the chord l of the wing and the thickness of the wing d ; for d both the ratios d/l and d/d_A (relation to the diameter of the jet) are of importance. Approximate formulas for the lift to be expected were given. A few short tests treat the case of a propulsion unit in yawed flow. According to the results it is possible to fix, for instance, the position of a tail unit in such a way that the influence in the case of straight flow is only very slight. Noticeable and unwelcome effects are to be expected only when the jet is pointed directly at the wing or is tangent to it. Therefore, for a project, knowledge of the course of the jet under as many different flight conditions as possible should be emphasized. These questions are also especially important with respect to the problem treated here, because the spreading of the jet depends considerably upon the form of the fillet for the installation and upon the possibility of a sufficient ventilation from all sides. This dependency is especially obvious where the propulsion unit has been installed on the outside.

Translated by Mary L. Mahler
National Advisory Committee for Aeronautics

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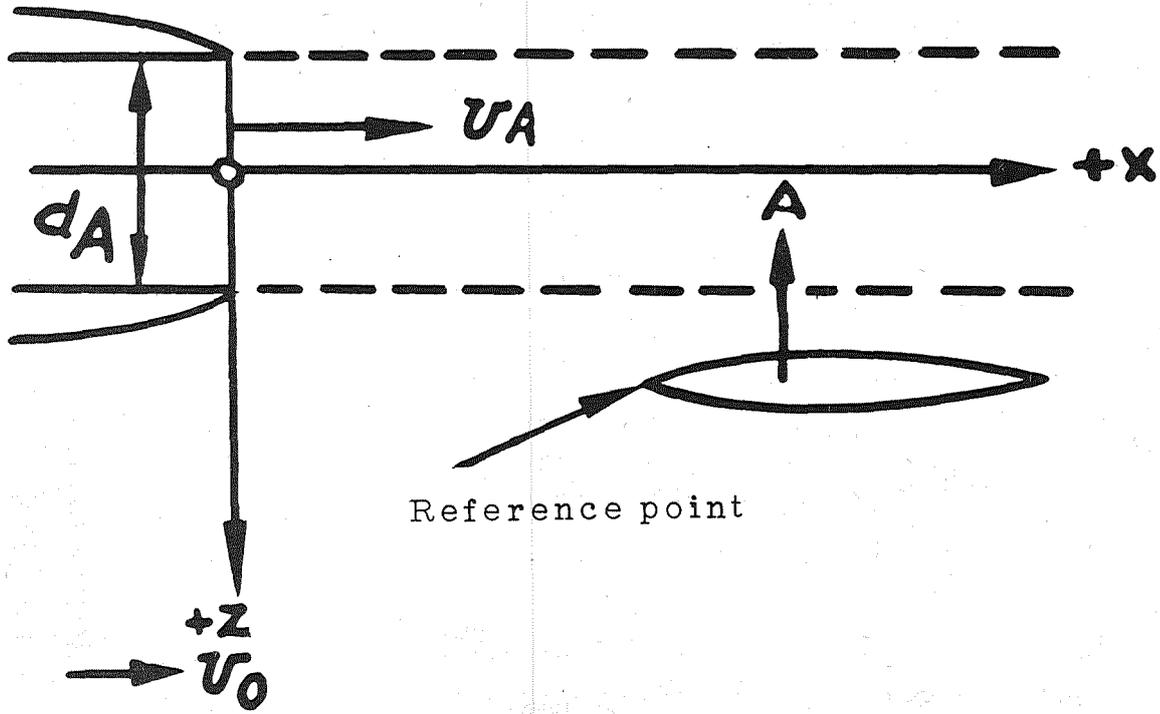


Figure 1.

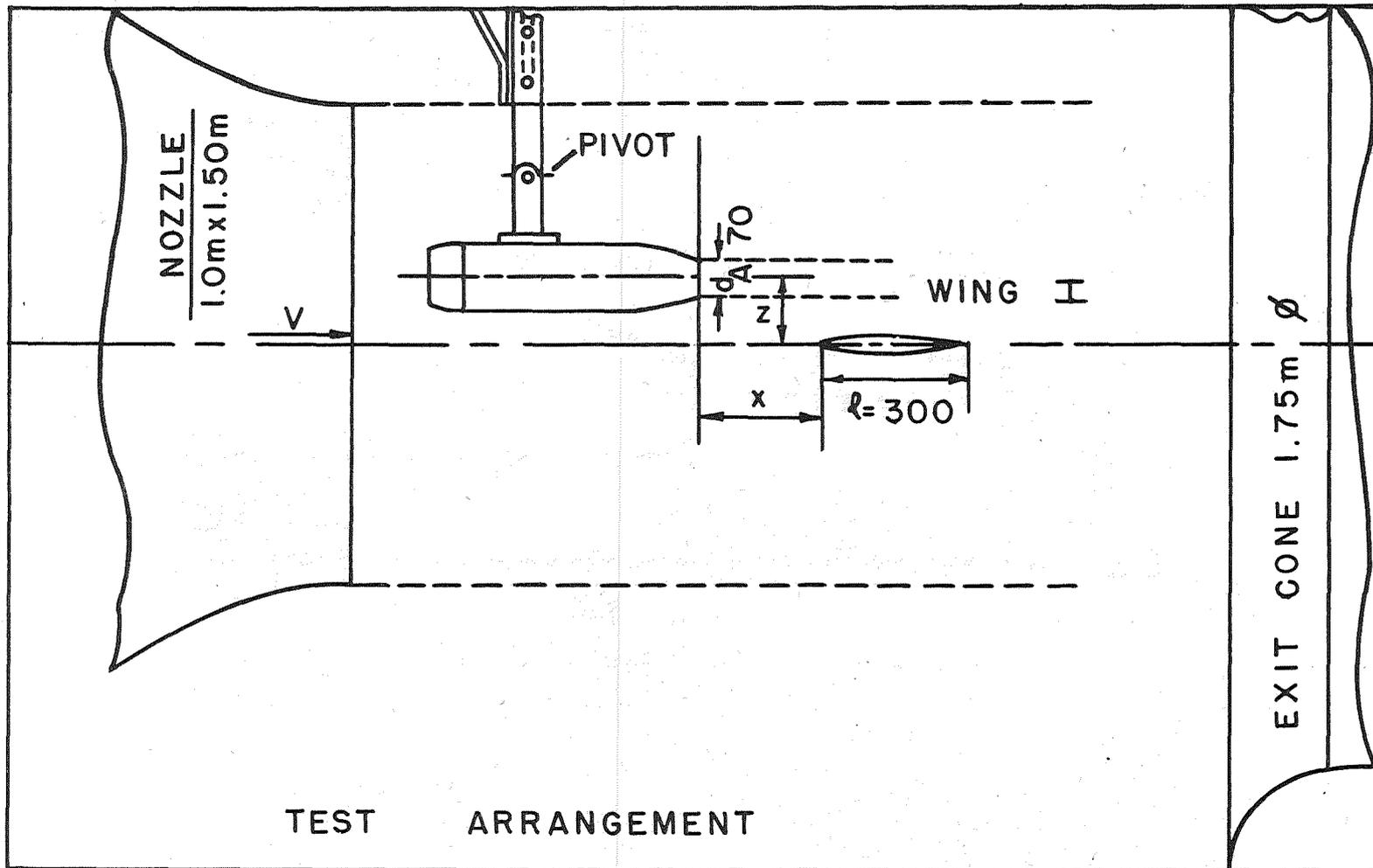


Figure 2.

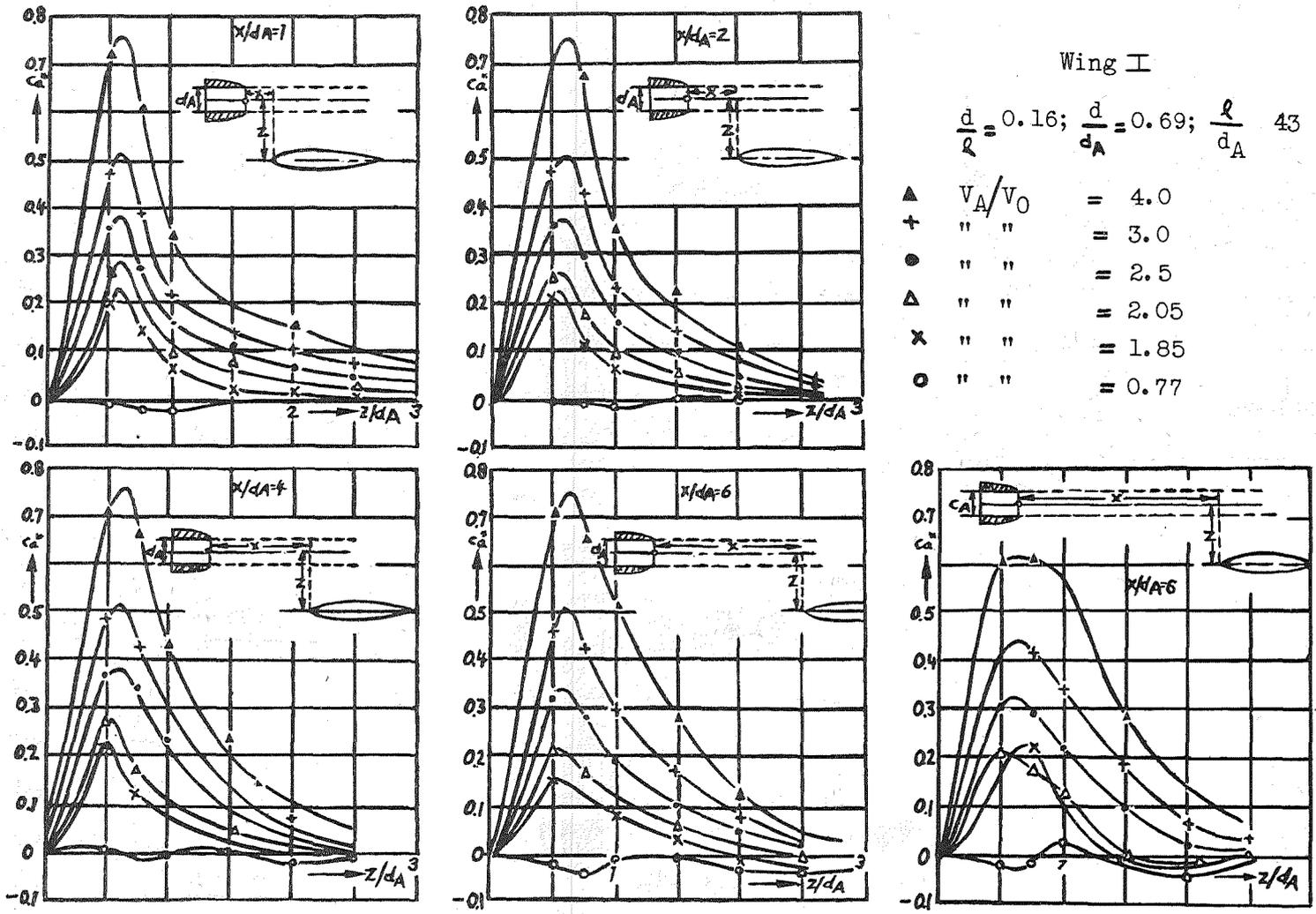
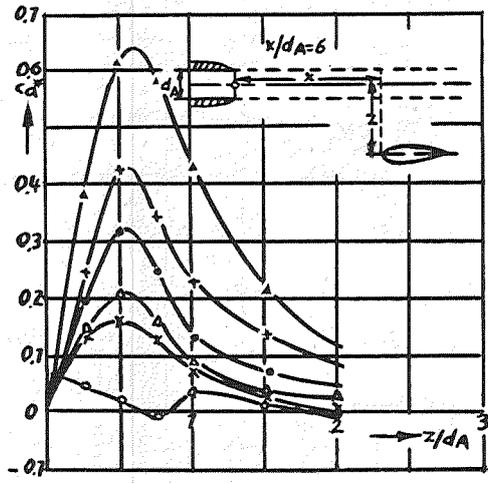
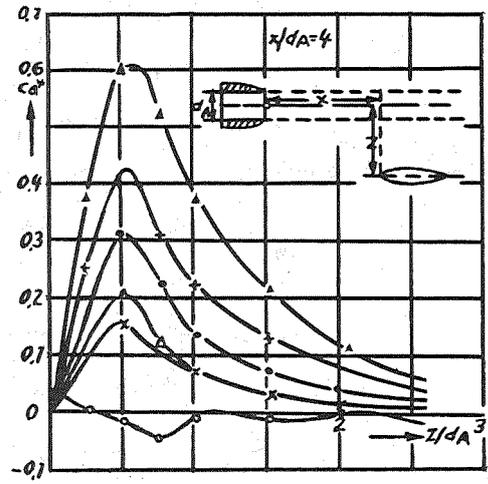
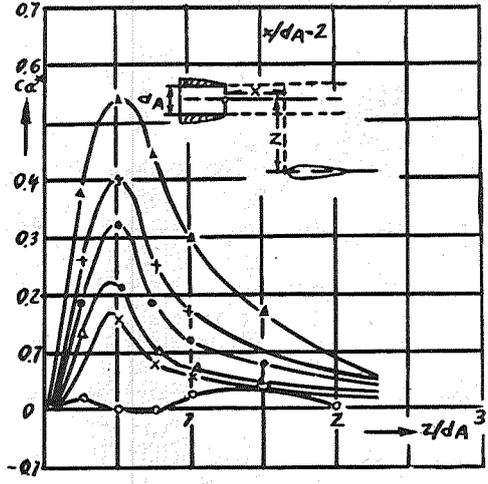
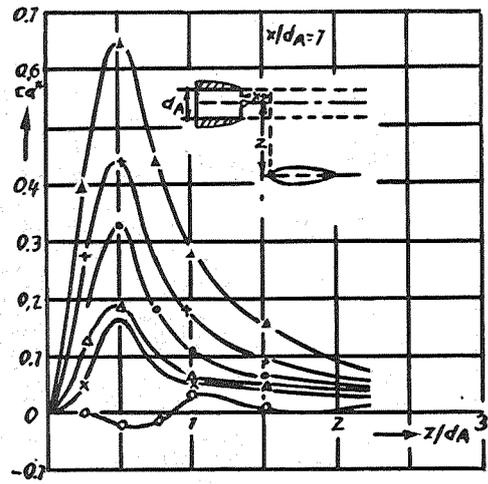


Figure 3.



Wing II
 $\frac{d}{r} = 0.10; \frac{d}{d_A} = 0.25; \frac{l}{d_A} = 2.5$

- ▲ $V_A/V_0 = 4.0$
- + " " = 3.0
- " " = 2.5
- △ " " = 2.05
- × " " = 1.80
- " " = 0.77

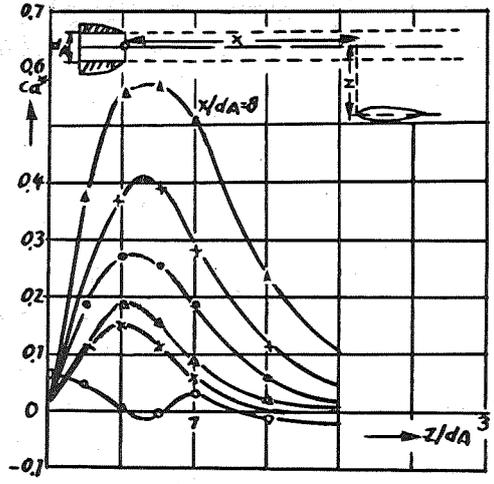
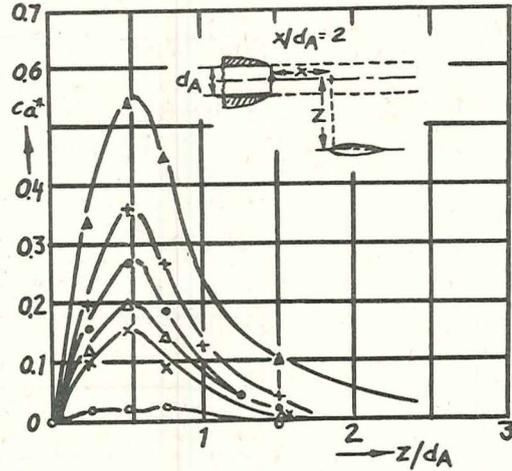
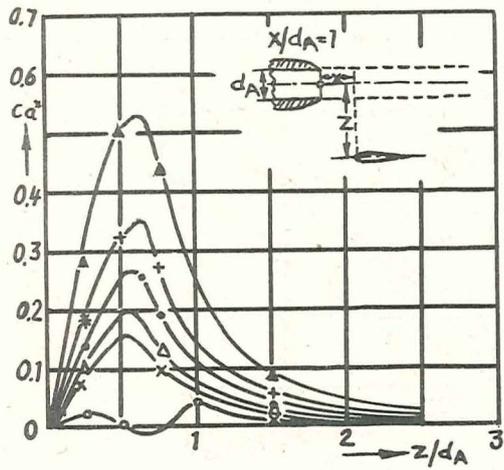


Figure 4.



Wing 
 $\frac{d}{l} = 0.09; \frac{d}{d_A} = 0.16; \frac{l}{d_A} = 1.8$

- ▲ $V_A/V_0 = 4.0$
- + " " = 3.0
- " " = 2.5
- △ " " = 2.05
- x " " = 1.85
- " " = 0.77

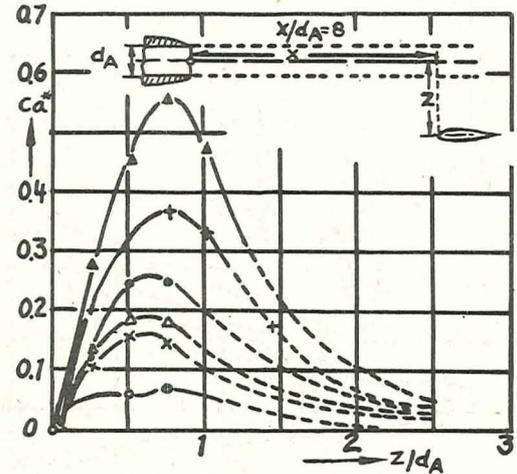
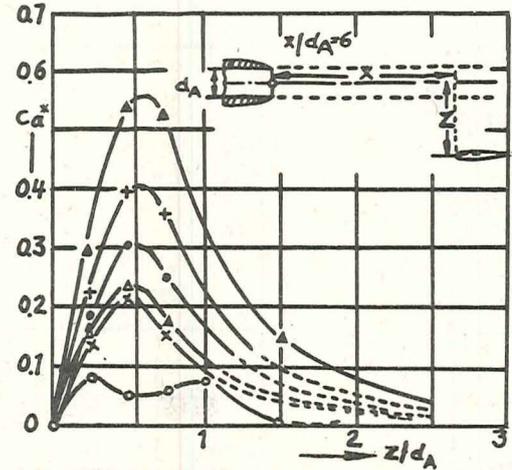
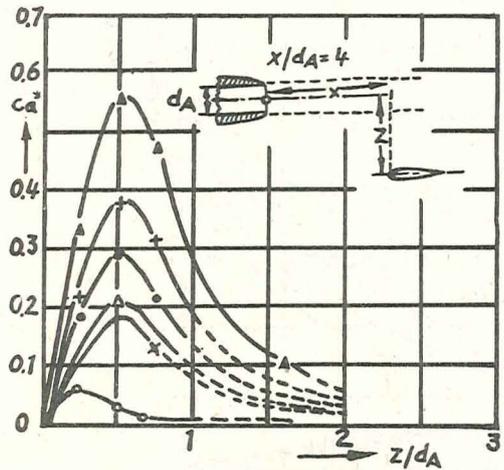


Figure 5.

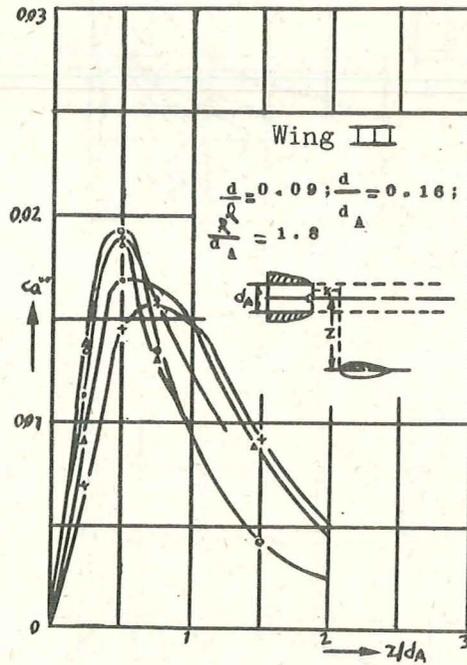
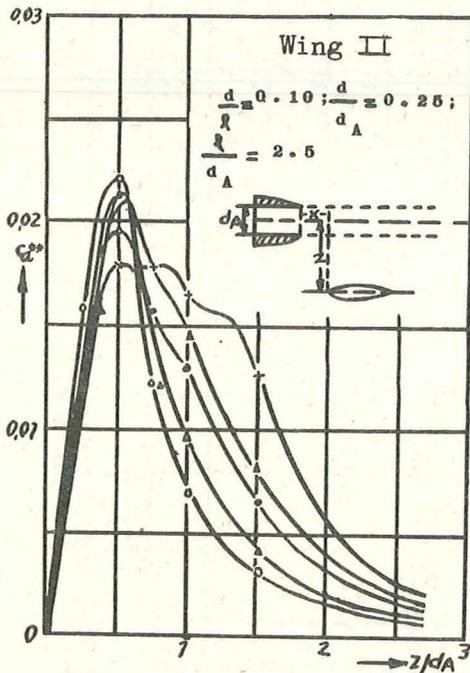
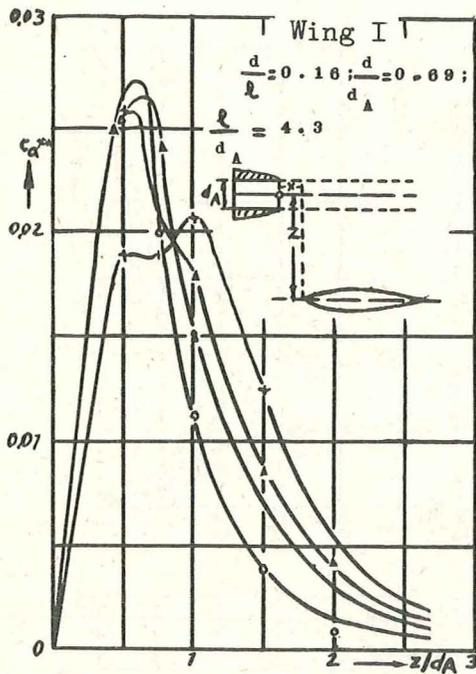


Figure 6.

Wing II $\frac{d}{r} = 0.70$; $\frac{d}{d_A} = 0.25$; $\frac{r}{d_A} = 2.5$ $\alpha = 3^\circ$

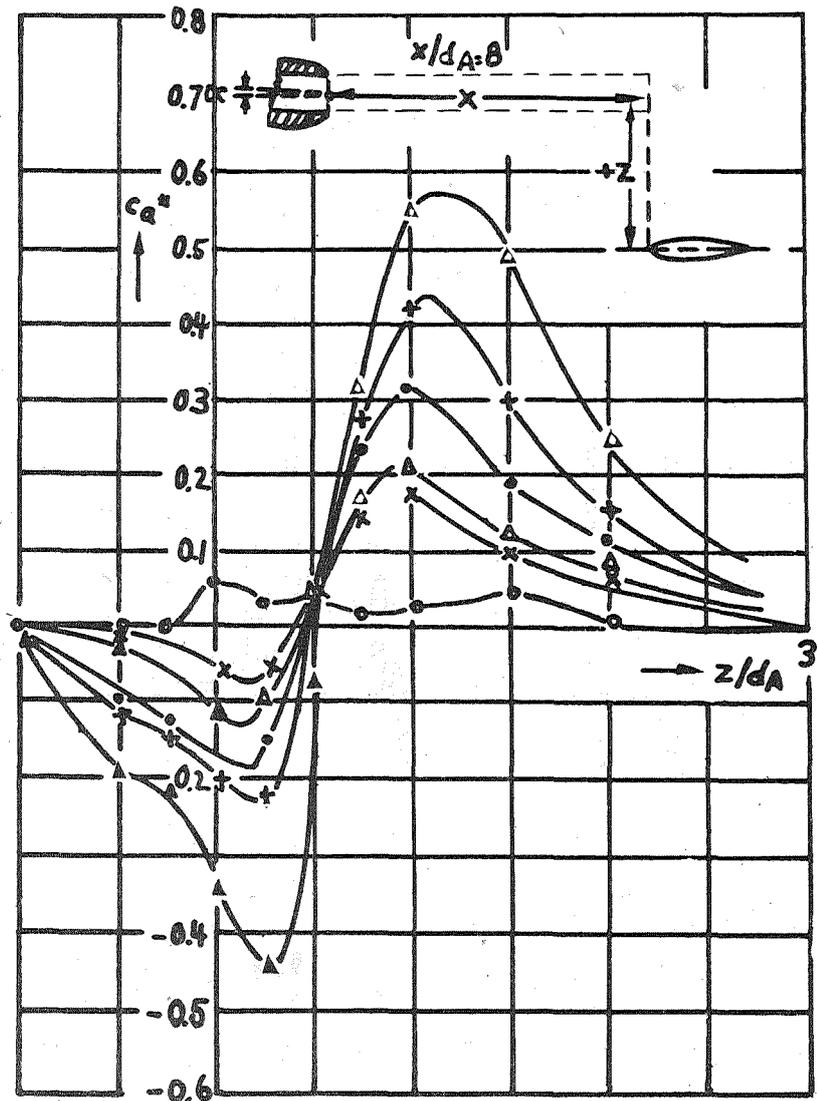
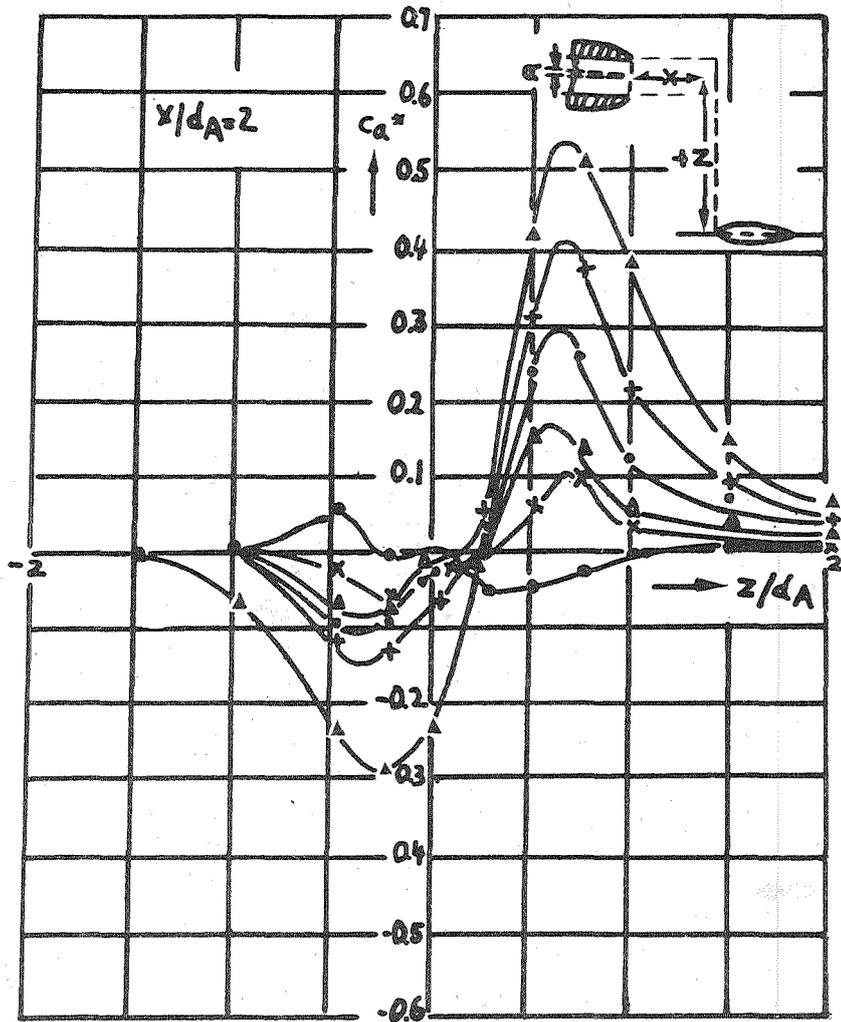
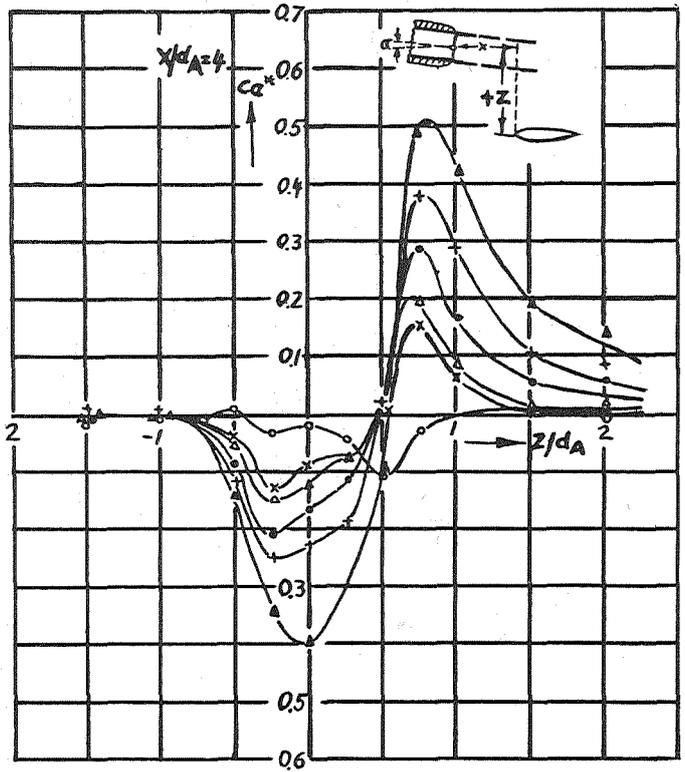


Figure 7.



Wing II

$$\frac{d}{R} = 0.10; \quad \frac{d}{d_A} = 0.25; \quad \frac{R}{d_A} = 2.5$$

$$\alpha = 6^\circ$$

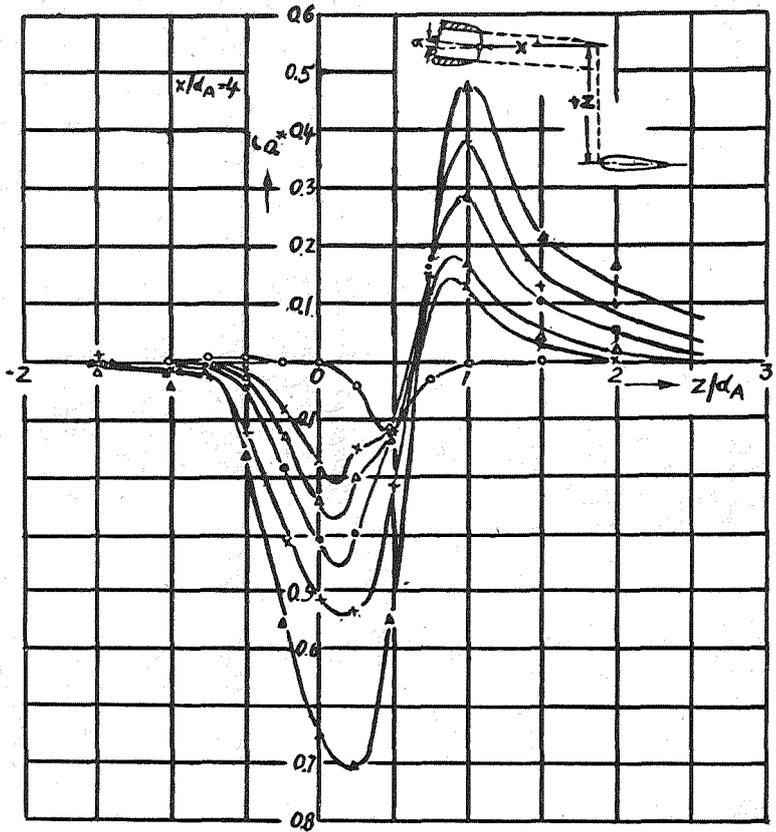


Figure 8.

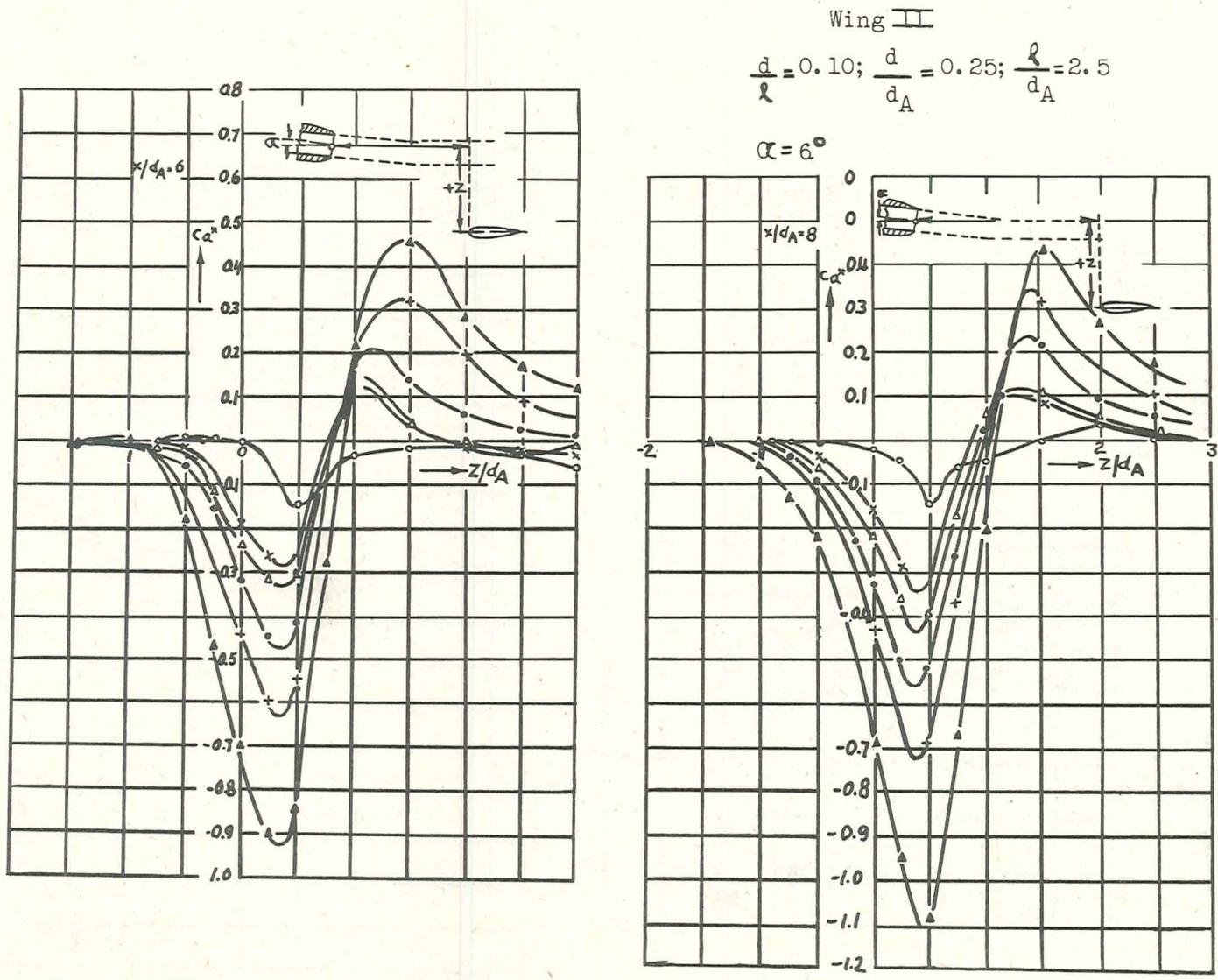
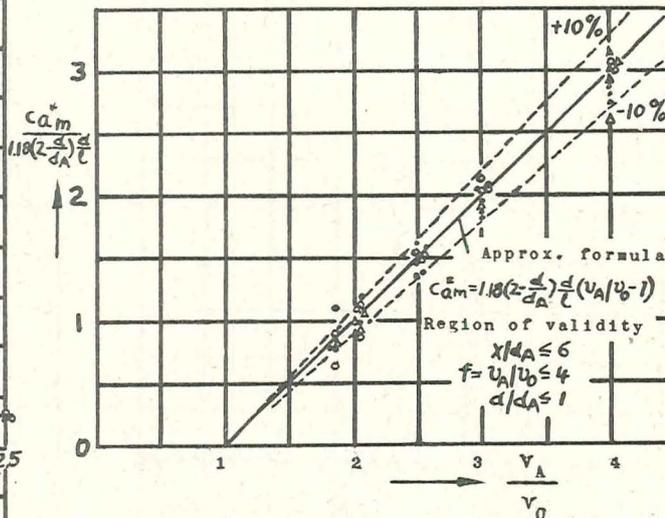
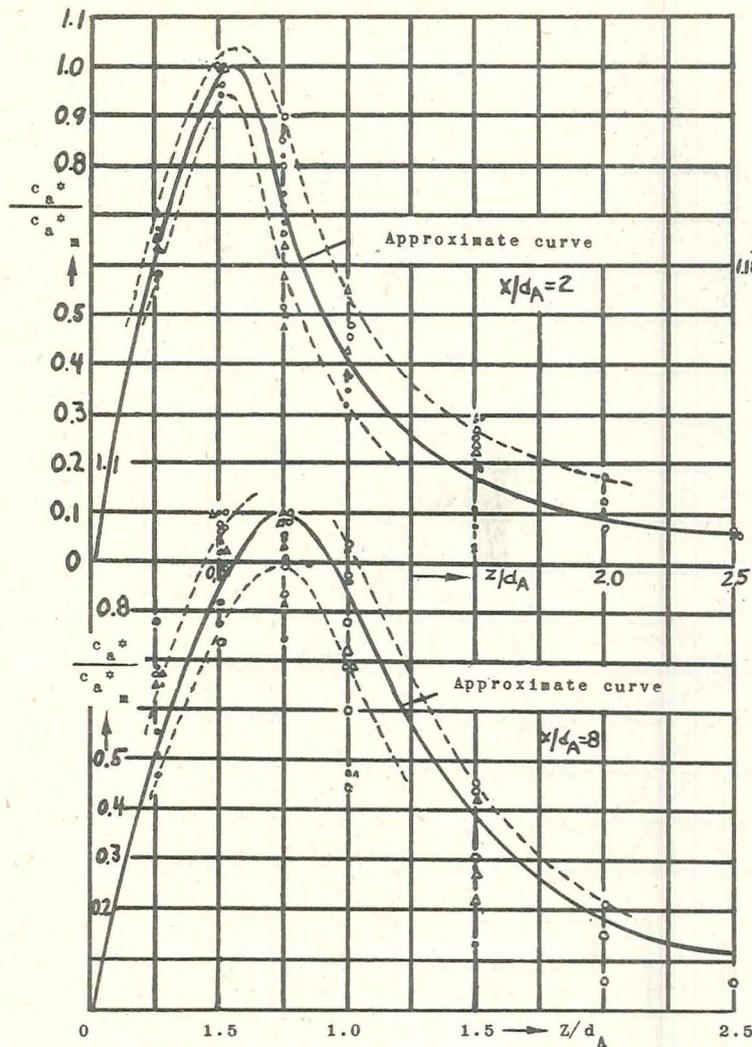


Figure 9.



Comparison of the approximate curves
with test values

Wing	d/d_A	d/l
○ I	0.69	0.16
△ II	0.25	0.10
● III	0.16	0.09

Figure 10.

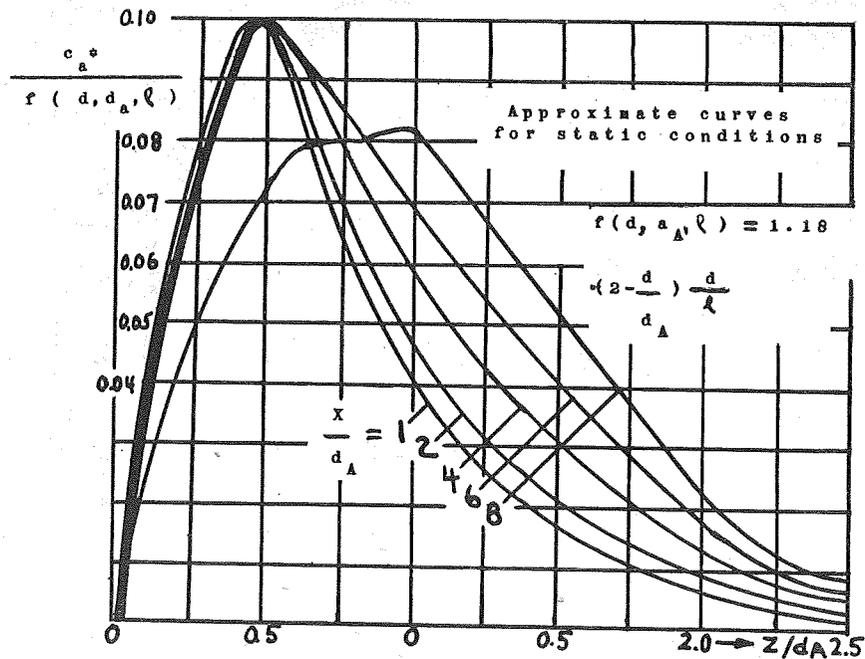
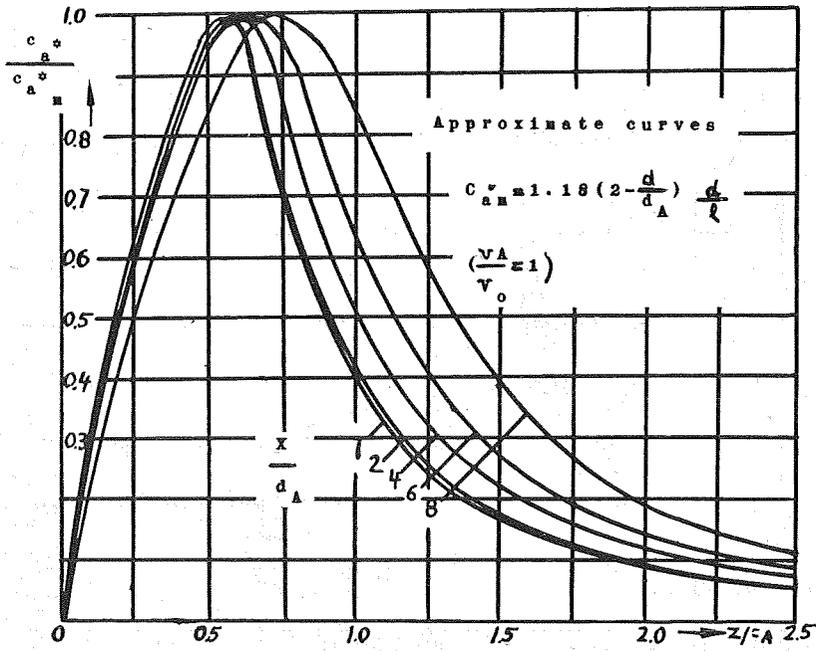


Figure 11.

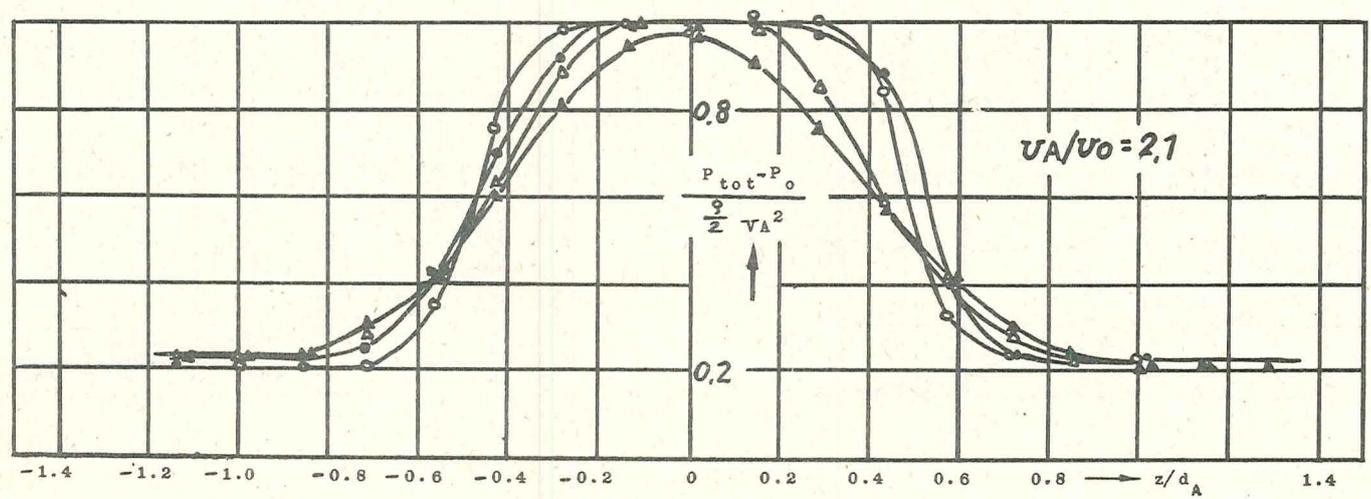
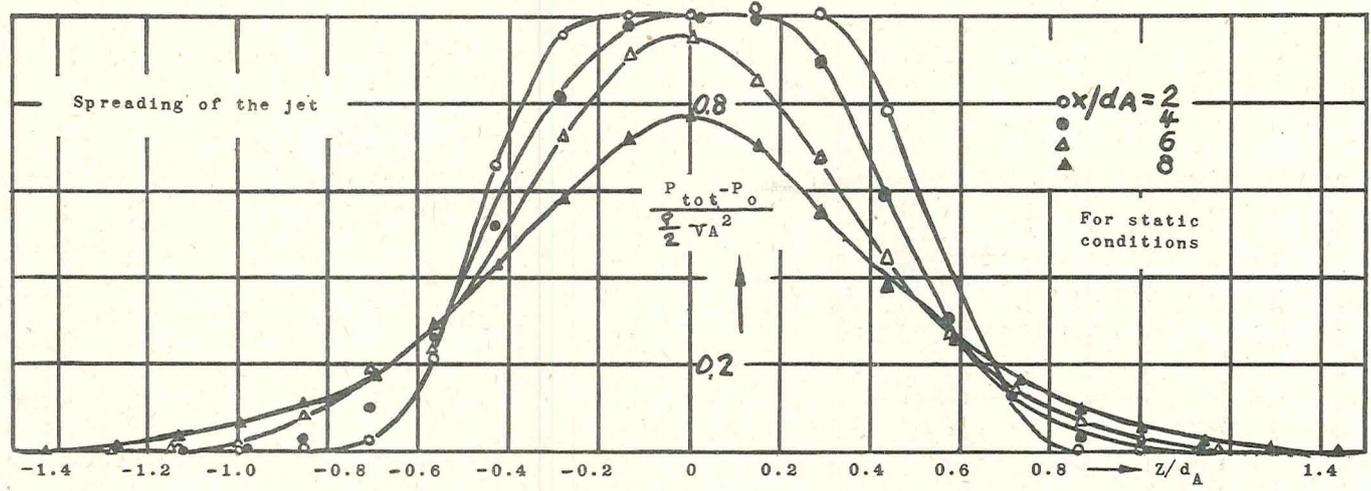


Figure 12.