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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM

No. 1191

VENTURI TUBE WITH VARYING MASS FLOW

By B. Regenscheit

TRANSLATION

“Venturidüse mit veränderlichem Durchfluss”  
Deutsche Luftfahrtforschung, Forschungsbericht Nr. 1945



Washington  
March 1948

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VENTURI TUBE WITH VARYING MASS FLOW\*

By B. Regenscheit

**Abstract:** Measurements on three tubes with flow regulated by suction at the trailing edge of the tube are described. It was possible to vary the mass of air flowing through the tube over a large range. Such tubes could, circumstances permitting, be used for shrouded propellers. Suitable tests have been prepared.

**Outline:**

- I. Introduction
- II. Model and Test Arrangements
- III. Evaluation
- IV. Results
- V. General Behavior of the Tubes
- VI. Summary

Appendix  
References

I. INTRODUCTION

A venturi tube with varying flow can be useful for several technical purposes. For instance, the static thrust of a shrouded propeller could be increased further by means of that tube than proved possible so far. (See references 1 and 2.)

Since the circulation of a wing could be changed without changing the angle of attack by suction at the trailing edge of the wing (reference 3), the idea of controlling the flow of a venturi tube in the same way seemed obvious.

The present tests which were carried out by R. Gerhard and E. Hansen give a first survey of the possible changes in flow.

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\*"Venturidüse mit veränderlichem Durchfluss."  
Zentrale für wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) Berlin-Adlershof, Forschungsbericht Nr. 1945, May 19, 1944.

## II. MODELS AND TEST ARRANGEMENTS

Three tubes, in two test series, were investigated in the wind tunnel (elliptic tube  $0.73 \times 1.03$  meters). The main dimensions of these tubes are given in figure 1; they differ from one another by the magnitude of the diffuser angle. The geometrical area ratios given with the diffusers are  $\frac{F_a}{F_i} = 1.0, 1.85, \text{ and } 2.87$

( $F_a$  = outlet area,  $F_i$  = minimum inside flow area). In a special test series it was investigated for the tube  $\frac{F_a}{F_i} = 1$  with more detail whether split rings of various shape arranged at the outlet of the tube yield further increases in efficiency.

The suction mass was changed while the wind velocity was retained unchanged. Moreover, for a maximum suction mass the wind velocity was decreased in order to obtain especially high mass coefficients. The maximum wind velocity was 40 meters per second.

Flow observations were made also on a model of the tube  $\frac{F_a}{F_i} = 1.88$  on the scale 1:2 in the small water channel of the AVA.

## III. EVALUATION OF THE TEST RESULTS

The static pressure at the minimum cross section of the tube was used for determination of the velocity ratio  $\frac{V_i}{V_\infty}$  according to Bernoulli's equation

$$\frac{V_i}{V_\infty} = \sqrt{1 - \frac{p_{st} - p_\infty}{q_\infty}}$$

- $P_{st}$  static pressure at the minimum cross section of the tube, kilograms per meter<sup>3</sup>
- $P_{\infty}$  static pressure far from the tube
- $q_{\infty}$  free-stream stagnation pressure, kilograms per meter<sup>2</sup>
- $v_i$  velocity at the minimum cross section of the tube, meters per second
- $v_{\infty}$  free-stream velocity, meters per second

This figure also gives the measure for the increase in quantity in the circulation increase at the tube profile for the case that this static pressure (which was measured at the wall) remains constant over the whole minimum tube cross section (which actually is not exactly the case). The quantity  $v_i F_i$  calculated from it is further on called "apparent volume flow." To make the effect of single influences easy to survey, the test results were therefore plotted so that over the dimensionless sucked fluid volume

$$c_Q = \frac{Q_A}{v_{\infty} F_i} = \frac{Q_A}{Q_{\infty}}$$

$Q_A$  = sucked fluid volume, meters<sup>3</sup> per second

$$F_i = \frac{D_i^2 \pi}{4}, \text{ meters}^2$$

the value  $\frac{v_i}{v_{\infty}}$  was represented.

The actual increase of the volume flow was measured in a special test by measurement of the velocity distribution in a tube cross section ahead of the suction slot. Therewith the volume flow inside the tube is

$$Q_i = \int_0^R v_v 2\pi r dr$$

$v_v$  = local velocity measured in the tube, meters per second

If one refers this volume to the comparative volume

$$Q_{\infty} = R_i^2 \pi v_{\infty}$$

$R_i$  = inside radius, meters

one obtains

$$\frac{Q_i}{Q_{\infty}} = \frac{2}{R_i^2} \int_0^{R_i} \frac{v_v}{v_{\infty}} r dr$$

The ratio of volume flow within the tube to the apparent volume flow (which resulted from  $\frac{v_i}{v_{\infty}}$ ) was expressed by a factor K:

$$K = \frac{Q_i}{v_i F_i} = \frac{Q_i}{Q_{\infty}} \left( \frac{v_{\infty}}{v_i} \right)$$

The measurement of the volume flow  $Q_i$  was made ahead of the suction slot. However, a part of this quantity is sucked off. The ratio of the volume flow at the end of the tube to the comparative volume is, therefore,

$$\xi_Q = \frac{Q_i}{Q_{\infty}} - c_Q$$

For the ratio of the actual volume flow  $Q = Q_i - Q_A$  to the apparent volume flow  $v_i F_i$  one therefore obtains

$$K \xi = \xi_Q \frac{v_{\infty}}{v_i}$$

The suction pressure in the suction chamber of the tube was referred to the stagnation pressure of the oncoming air

$$c_p = \frac{p_K}{q_{\infty}} \quad p_K = \text{static pressure in the suction chamber}$$

In one case (tube  $\frac{F_i}{F_a} = 1$ ) the drag coefficient of the tube also was ascertained. It was referred once ( $c_{wD}$ ) to the inside flow cross section, but then also to the shroud area ( $c_{wM}$ ), to have a comparison with customary values for wings

$$c_{wD} = \frac{W}{\frac{\pi}{4} D_i^2 q_\infty}$$

$$c_{wM} = \frac{W}{q_\infty D_m \pi t}$$

#### IV. RESULTS

The values  $v_i/v_\infty$  for the three diffusers without suction are compared in figure 2\* with values as they would theoretically result, according to a treatise by Betz (reference 4) if one presupposes various diffuser efficiencies. The tube without diffuser yields  $v_i/v_\infty = 1$ . This tube corresponds to the theoretical values. The energy loss at the inlet and the narrowing of the cross section at the exit through the boundary layer (due to which the velocity ratio ought to be  $<1$ \*\*) is so slight that these influences were negligible for the measurement. At  $F_a/F_i = 1.88$  the measured result corresponded to the value  $v_i/v_\infty$  with a diffuser efficiency  $\eta_D = 0.95$  and at  $F_a/F_i = 2.85$  to the value calculated with  $\eta_D = 0.92$ . These diffuser efficiencies appear to be rather high. One may suppose that the static pressure measured at the wall of the tube is not equal over the whole area of the tube, even without suction. The velocity at the wall is, due to the circulation of the annular profile, higher than over the cross section; this circumstance is clearly manifest at the later measurements with suction. The actual efficiency is probably smaller than given here.

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#### Reviewer's Notes:

\*This figure is believed to be in error in its present form. The ordinate scale label  $v_i/v_\infty$  should read  $v_\infty/v_i$ . In references made herein to figure 2, the term  $v_i/v_\infty$  should be changed to  $v_\infty/v_i$ .

\*\*The statement "(... the velocity ratio ought to be  $<1$ )" should read "(... the velocity ratio ought to be  $>1$ )."

The values  $v_1/v_\infty$  for the three tubes as functions of  $c_Q$  that were obtained for various values  $s/D_1$  ( $s$  = protrusion of the outer shroud over the inner shroud, see fig. 1) are plotted in figure 3.

The largest values  $\frac{d(v_1/v_\infty)}{dc_Q}$  in the region of small  $c_Q$ -values are obtained with the tube without diffuser, obviously because already small quantities of the air to be sucked off further the circulation changing effect of the suction at the trailing edge. With a diffuser this effect can be reached only when the major part of the boundary-layer material is sucked off. The values obtained for  $\frac{d(v_1/v_\infty)}{dc_Q}$  are represented as functions of  $\frac{F_a}{F_i}$  in figure 4. For each tube there results an optimum protrusion  $s$  which increases with increasing diffuser angle. The value  $v_1/v_\infty$  for  $c_Q = \text{constant}$  is plotted versus  $s/D_1$  in figure 5. The optimum value  $s/D_1$  as a function of  $F_a/F_i$  is also represented in figure 4.

A split ring was fitted to the trailing edge of the tube on the tube without diffuser ( $\frac{F_a}{F_i} = 1$ ) in order to find out how far it can influence the effect of the tube. The result is represented in figures 6 and 7. It is obvious that a split ring has a noteworthy effect. In figure 8 the increase of the value  $v_1/v_\infty$  is plotted as a function of  $D_s/D_1$  (split-ring diameter/inner-tube diameter);  $v_1/v_\infty$  increases for a large  $c_Q$  about linearly with the split-ring diameter.

The influence of the angle of attack of the split ring is especially noticeable for the increase  $\frac{d(v_1/v_\infty)}{dc_Q}$ . This increase is most rapid for the measurement with  $\eta = 30^\circ$  in the region between  $c_Q = 0$  and  $c_Q = 0.15$ .

Beyond this value the small incidence of the split ring ( $\eta = 30^\circ$ ) obviously prevents the full development of the stream line made possible by the suction at the trailing edge. The values  $v_1/v_\infty$  do not reach the values attained for the split angles  $60^\circ$  and  $90^\circ$ . The influence of the split ring was measured for two values of the protrusion  $s/D_1$ . With split ring, the flow is stable for the protrusion  $s/D_1 = 0.0113$ , which is too small without split ring because the effect of the suction mass sets in slower than usual. (Moreover, two different flow conditions may accidentally result.) The increase of the value  $v_1/v_\infty$  starts immediately

with a split ring. The value  $\frac{d(v_1/v_\infty)}{dc_Q}$  was represented as a function of the split-ring angle in figure 9. The larger protrusion  $s/D_1$  yielded the higher values of the increase in effect.

Figure 10 shows the result of the investigation of the actual mass flow. (Arrangement without split ring,  $s/D = 0.0286$ .) The variation of the local velocity is represented over the cross section for two suction masses ( $c_Q = 0.2$  and  $0.52$ ) on the left third. It is obvious how the flow velocity increases toward the wall of the tube with increasing suction mass. The flow velocity for the larger suction mass is higher over the whole cross section than for the small suction mass. However, oddly enough, there is an exception at the tube center: there the value of the flow velocity is smaller for a greater than for a smaller suction mass. We are going to verify this test result.

For comparison the velocity ratio  $v_1/v_\infty$ , the mass ratio  $Q_1/Q_\infty$  and the actual mass ratio  $(Q_1/Q_\infty - c_Q)$  are plotted over  $c_Q$  in the right third. The actual mass ratio reaches a maximum in this test at about  $c_Q = 0.3$ .

The ratios

$$K = \frac{Q_1/Q_\infty}{v_1/v_\infty} \text{ and } Kt = \frac{Q_1/Q_\infty - c_Q}{v_1/v_\infty}$$

are represented at the center of the figure.



The drag variation for the tube  $\frac{F_a}{F_i} = 1$  as a function of  $c_Q$  is represented in figure 11. For reasons of experimental technique it was not possible to continue the measurements beyond  $c = 0.14$ . The test result shows a steep decline of the drag coefficient with increasing  $c_Q$ . The presented test values contain the tube drag and the sink drag. The drag of the wires and of the suction tube is deducted. If one wanted the net profile drag of the tube ring the sink drag also would have to be deducted from the presented values. There results the peculiar fact that the profile drag then becomes thrust. At first one is inclined to look upon this fact as an error in measurement. However, this phenomenon was observed repeatedly (for wings alone with suction as well) and every time regarded as an error. One might suppose that when the suction mass is large, air particles which do not belong to the suction mass are accelerated by the sink effect near the slot. Thus originates the thrust which appears in the test. Several preliminary tests hint at the fact that the total pressure of the air particles leaving the tube will be somewhat higher for a large suction mass than for undisturbed flow. A special research project will resume this problem.

The measurements in the small water channel also were carried out for various values  $s/D_i$ . However, the most favorable value  $s/D_i$  was not identical with the one obtained in the wind tunnel. A larger protrusion had to be selected; the optimum protrusion  $s/D_i$  was 0.057. The values obtained for this protrusion are plotted in figure 12 and compared with the results of the best wind-tunnel measurements. The agreement of the test results is good. The measurement in the water channel was performed with two suction slot widths  $\delta$  in order to see the influence of these widths upon the negative suction pressure. Whereas no difference in suction pressure of any importance resulted, an influence of the width of the slot upon the course of  $v_i/v_\infty$  was noticeable: with the slot narrowing the steeper increase  $\frac{d(v_i/v_\infty)}{dc_Q}$  was obtained. For the narrower trailing-edge slot the value  $v_i/v_\infty$  without suction was already

smaller than for the wide slot. (To obtain the narrowing slot, the diameter of the outer tube at the trailing edge was decreased. Thus the flow through the tube at  $c_Q = 0$  was changed as observed.)

The influence of an oblique incidence of  $\pm 10^\circ$  was investigated in the water channel. No difference in the results of the measurements as compared with those for a flow incidence of  $0^\circ$  could be found. An investigation with split ring was not performed. One may suppose, however, that the sensitivity against oblique flow incidence would be slight in this case also. This conclusion may be drawn from a test of W. Krüger (reference 5) using a venturi tube with split flap. Krüger observed an independence of the test result for oblique incidence angles up to  $80^\circ$ .

The flow photographs from the water channel are shown in figure 13.<sup>1</sup> One can see very distinctly the course of the streamlines corresponding to a strong circulation around the annular profile. The figure also shows for comparison two wing sections with suction at the trailing edge so as to point out the analogy of the flow phenomena in both cases.

## V. GENERAL BEHAVIOR OF THE TUBES

The results of tests with tubes could be obtained for decreasing as well as for increasing mass if the protrusion  $s$  exceeded a certain limiting value. When a smaller value than the limiting value of the protrusion was selected, two different values could be measured for  $v_1/v_\infty$  according to whether one proceeded from a large  $c_Q$  to a small one or from a small  $c_Q$  to a large one. Such a result for the tube  $F_a/F_1$  is plotted in figure 3. When the protrusion was smaller than its limiting value the flow oscillated between the upper and lower test value.

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<sup>1</sup>The pictures for an oblique flow incidence of  $10^\circ$  were selected because they showed the flow most clearly of all photographs taken.

The tubes exhibit a certain sensitivity to bodies introduced inside. Figure 14 shows such a test result. An adjustable Prandtl tube had been built into the tube to measure the velocity distribution within the tube. However, the flow of the tube was so greatly disturbed by the support of the Prandtl tube that the tube did not work beyond  $c_Q = 0.4$ . In the tests using the tube

$\frac{F_a}{F_i} = 1$  which are represented in figure 10 the Prandtl

tube was inserted into the tube from behind. Thus the disturbance was not quite as large. Yet one notices that compared with the measurements without Prandtl tube (fig. 3) the course of  $v_i/v_\infty$  over  $c_Q$  for high  $c_Q$ -values already somewhat deviates toward smaller  $v_i/v_\infty$ -values.

## VI. SUMMARY AND PROSPECT OF FURTHER RESEARCH WORK

The present results of preliminary tests indicate that the circulation around annular profiles also can be increased by means of suction at the trailing edge. Thus the flow through Venturi tubes could be changed by suction. The greatest change in flow, expressed by the

value  $\frac{d(v_i/v_\infty)}{dc_Q}$ , could, for a small suction mass, be

obtained by the tube without diffuser  $\left(\frac{F_a}{F_i} = 1\right)$ . (See

fig. 4). The effect of the suction upon the flow through the tubes could be increased still more by split rings at the trailing edge of the tube. The flow through the tubes was sensitive to disturbances that were introduced (Prandtl tube with support).

Further research work will deal with tubes of smaller chord. First of all an application of these tube rings to shrouded propellers will be tried. Thus it will, circumstances permitting, be possible to increase the thrust in slow motion more than by a normal propeller shroud. Special tests will have to show whether it is possible to increase also the static thrust. In this case

there exists no circulation around the annular profile; the flow will be only forced to expand at the exit of the tube.

Translated by Mary L. Mahler  
National Advisory Committee  
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## APPENDIX

CONSIDERATIONS CONCERNING THE APPLICATION OF THE  
VENTURI TUBE WITH VARIABLE MASS FLOW  
TO SHROUDED PROPELLERS

To judge the usefulness of a shrouding of a propeller one may have recourse to the momentum theory. According to this theory the power coefficient  $c_L$  required for obtaining a certain thrust coefficient  $c_s$  for unshrouded propellers will be

$$c_L = \frac{c_s}{2} \left( \sqrt{1 + c_s} + 1 \right)$$

For a shrouded propeller this value will be, as can be easily derived,

$$c_L = \frac{c_{sM}}{4} \left( \sqrt{\frac{2c_{sM}}{\alpha} + 1} + 3 \right)$$

$$c_L = \frac{L}{\frac{\rho v^3}{2} F}$$

$$c_{sM} = \frac{S}{\frac{\rho}{2} v^2 F}$$

The value  $\alpha$  is the ratio of the cross-sectional area of the air stream far behind the propeller to the propeller-disc area.

If  $c_L$  shall be the same in both cases, with and without shroud, then there is

$$\frac{c_s}{2} \left( \sqrt{1 + c_s} + 1 \right) = \frac{c_{sM}}{4} \left( \sqrt{\frac{2c_{sM}}{a} + 1} + 3 \right)$$

$c_s$  here stands for the thrust coefficient without shroud and  $c_{sM}$  for the thrust coefficient of the shrouded propeller.

Two special cases can be read off immediately from this equation:

1. If  $c_s$  is very large,  $c_{sM}$  also is very large and

$$\sqrt{\frac{c_s^3}{4}} = \sqrt{\frac{c_{sM}^3}{3a}}$$

$$\frac{c_{sM}}{c_s} = \sqrt[3]{2a}$$

This relation was already derived repeatedly (reference 2 and reference 6). It is mostly expressed in  $k_s$ -values (in order to evade the difficulty for  $c_s = \infty$ ) and then reads:

$$\frac{k_{sM}}{k_s} = \sqrt[3]{2a}$$

2. The result for  $a = \infty$  is

$$\frac{c_{sM}}{c_s} = \frac{1}{2} \left( \sqrt{1 + c_s} + 1 \right)$$

This relation shows that a stream expansion behind the propeller is very useful only for high  $c_s$ -values; for small  $c_s$ -values, for instance  $c_s = 1$ , only a value  $c_{sM}/c_s = 1.207$  can be obtained in this limiting case.

The value  $c_{sM}/c_s$  which is theoretically obtainable for various values  $\alpha$  and  $c_L$  was calculated and plotted in figure 15. The quantity  $\frac{1}{\sqrt{c_L}}$  was selected as abscissa to make the representation of a large  $c_L$ -region possible. (The increase of this value corresponds to increasing speed.) It can be seen clearly that the effect of the tube  $(c_{sM}/c_s)$  diminishes with increasing speed and also that very high  $\alpha$ -values are useful only for very low speed.

The stream deformation which was expressed by the number  $\alpha$  is, according to an investigation by Krüger (reference 2), independent of  $c_s$  within the limits observed there. It depends (under the assumption of the flow wetting the surface) only on the shape of the tube. One may assume that the same is valid for the pattern of the flow behind the tube which is enforced by the suction at the trailing edge. The velocity ratio  $K\frac{1}{2}$  would then have to correspond to the value  $\alpha$ .

As was shown, about  $K\frac{1}{2} = 2$  was reached. (For propeller shrouds without suction so far about  $\alpha = 1$ .) One may assume that for static conditions with the propeller in motion also the air jet flowing through the tube can be so expanded by the suction behind the tube that a diffuser flow corresponding to an  $\alpha = 2$  will result. Without propeller shroud, according to the momentum theory,  $\alpha = 1/2$ . Therefore it ought to be possible to increase the static-thrust ratio by means of a shroud with suction to  $\frac{c_{sM}}{c_s} = 1.59$  ( $c_L = \infty$ ,  $\frac{1}{\sqrt{c_L}} = 0$ ).

(With a shroud without suction  $a = 1$  only  $\frac{c_{sM}}{c_s} = 1.26$  could be obtained.)

The operation of the tube in motion depends largely on the load coefficient of the propeller. This load coefficient is for the plane in motion:

$$c_s = \frac{S}{\frac{\rho v^2 F_S}{2}} = \frac{G \sin \gamma}{\frac{\rho v^2 F_S}{2}} + \frac{W}{\frac{\rho v^2 F_S}{2}}$$

$$= \frac{G F \sin \gamma}{\frac{\rho v^2 F F_S}{2}} + \frac{W}{\frac{\rho v^2 F_S}{2}} \frac{F}{F} = c_{a \frac{F}{F_S}} \tan \gamma + c_{w \frac{F}{F_S}}$$

G gross weight, kilograms

W drag, kilograms

$F_S$  propeller-disc area, meter<sup>2</sup>

F wing area

v flight velocity

$\gamma$  inclination of the trajectory of the airplane

$c_a$  lift coefficient

$c_w$  drag coefficient

If one divides  $c_w$  up into the induced drag and the profile drag,  $c_s$  is

$$c_s = \frac{F}{F_S} \left[ c_{w_r} + c_a \left( \tan \gamma + \frac{c_a}{\pi \Lambda} \right) \right]$$

$\Lambda$  aspect ratio of the wings

$c_{w_r}$  residual drag coefficient



In modern airplanes  $\frac{F}{F_S}$  is about = 5. The  $c_s$ -values obtainable with this  $\frac{F}{F_S}$  immediately after the take-off and for the ascent for high  $c_a$ -values are about  $c_s = \frac{1}{4}$ .

Tests performed for instance by Krüger show that the thrust ratio  $c_{sM}/c_s$  for small advance ratios (up to about 0.25) is mostly larger than calculated. The reason is probably that the flow at the propeller blade without propeller shroud is partially separated at the blades, especially for a high load coefficient. By means of the propeller shroud the flow is induced to wet the surface. Thereby the blade thrust increases. This effect of the propeller shroud is more favorable than the results obtained by the momentum theory. A further effect of the same kind results from the decrease of the induced drag of the propeller blade since the shroud has the same effect as an end plate at the tip of the propeller blade.

Before making application of a propeller shroud with suction the question of the power unit for the suction apparatus will have to be solved. A possible way to a solution might be a combination of the starting aids used today, that is, of thrust nozzles with such a propeller shroud. The thrust nozzles would then have the effect of a jet apparatus and would move the suction air. The thrust of the propulsion nozzles need not be lost completely.

However, the main advantage of a shrouded propeller, especially with suction, will be obtained only when it will be used with an essentially higher load coefficient than has been used so far: the diameter of the propeller would have to be considerably decreased, the speed of the propeller increased. Krüger already followed up this idea in his treatise (reference 2). Engines with excessive speed (turbines) could then be used as power units. The high engine speed promises a decrease of the weight per unit power.

The sensitivity to disturbance which was observed for the introduction of bodies showed, for the bodies used, effects only in a range of operation of the tube which is not of interest for the practical application of the tube. One will have to find out whether a built-in blower with stator represents a disturbance sufficiently large as to render the whole arrangement useless.

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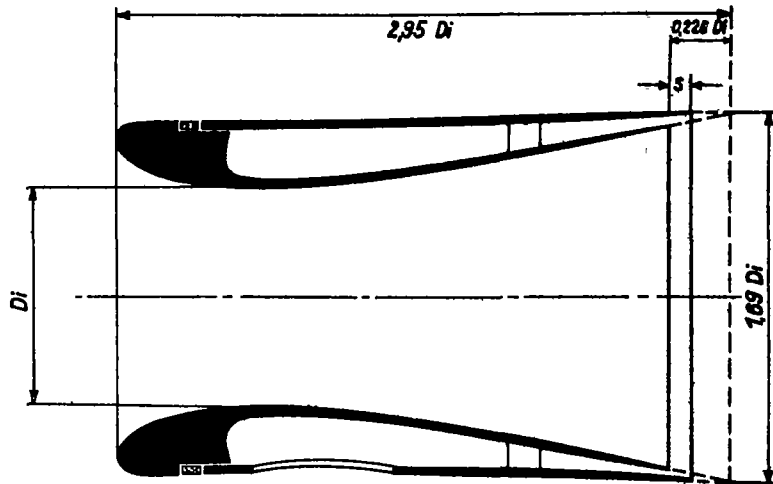
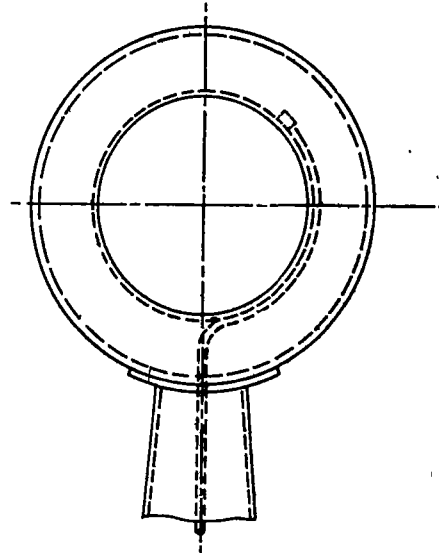
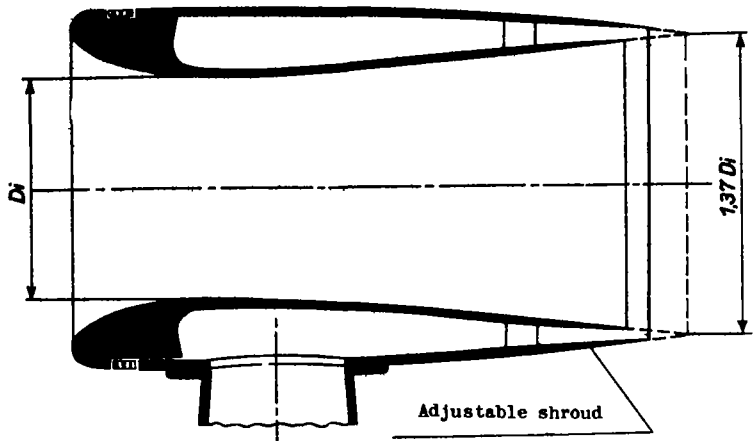
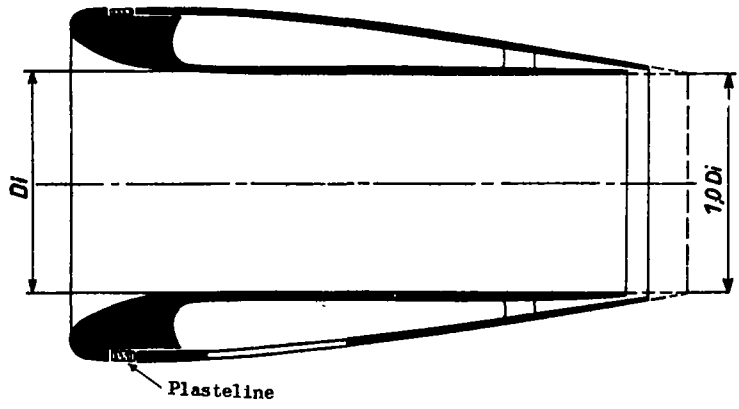


Figure 1 - Venturi tube with various flows.

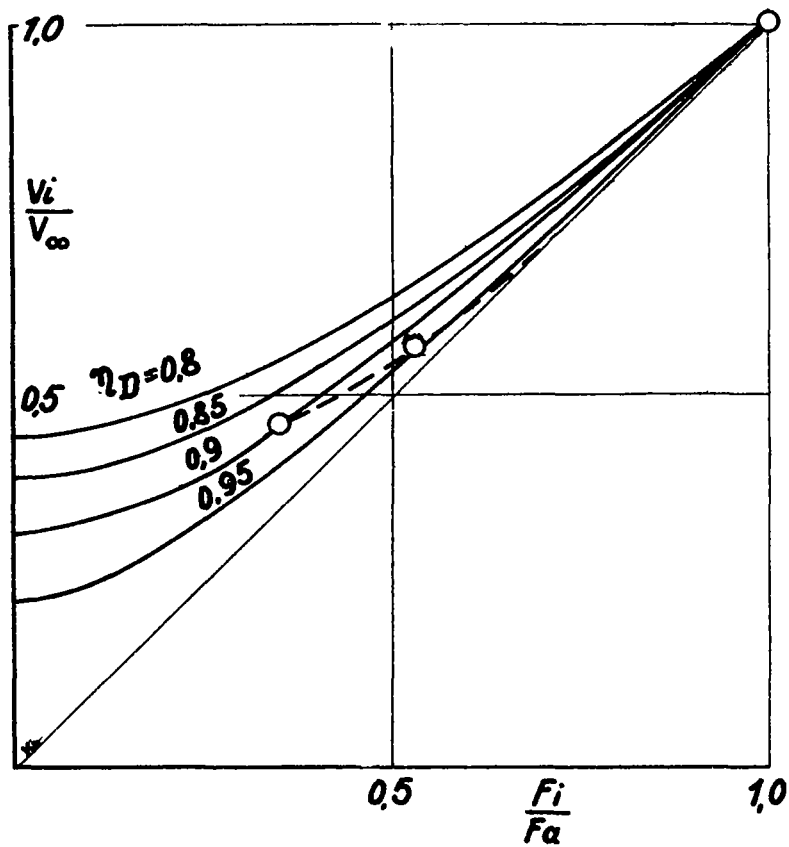


Figure 2 - Comparison of the values  $\frac{v_i}{v_\infty}$  of the tested tubes without suction with the values obtained by calculation for a given  $\eta_D$ .

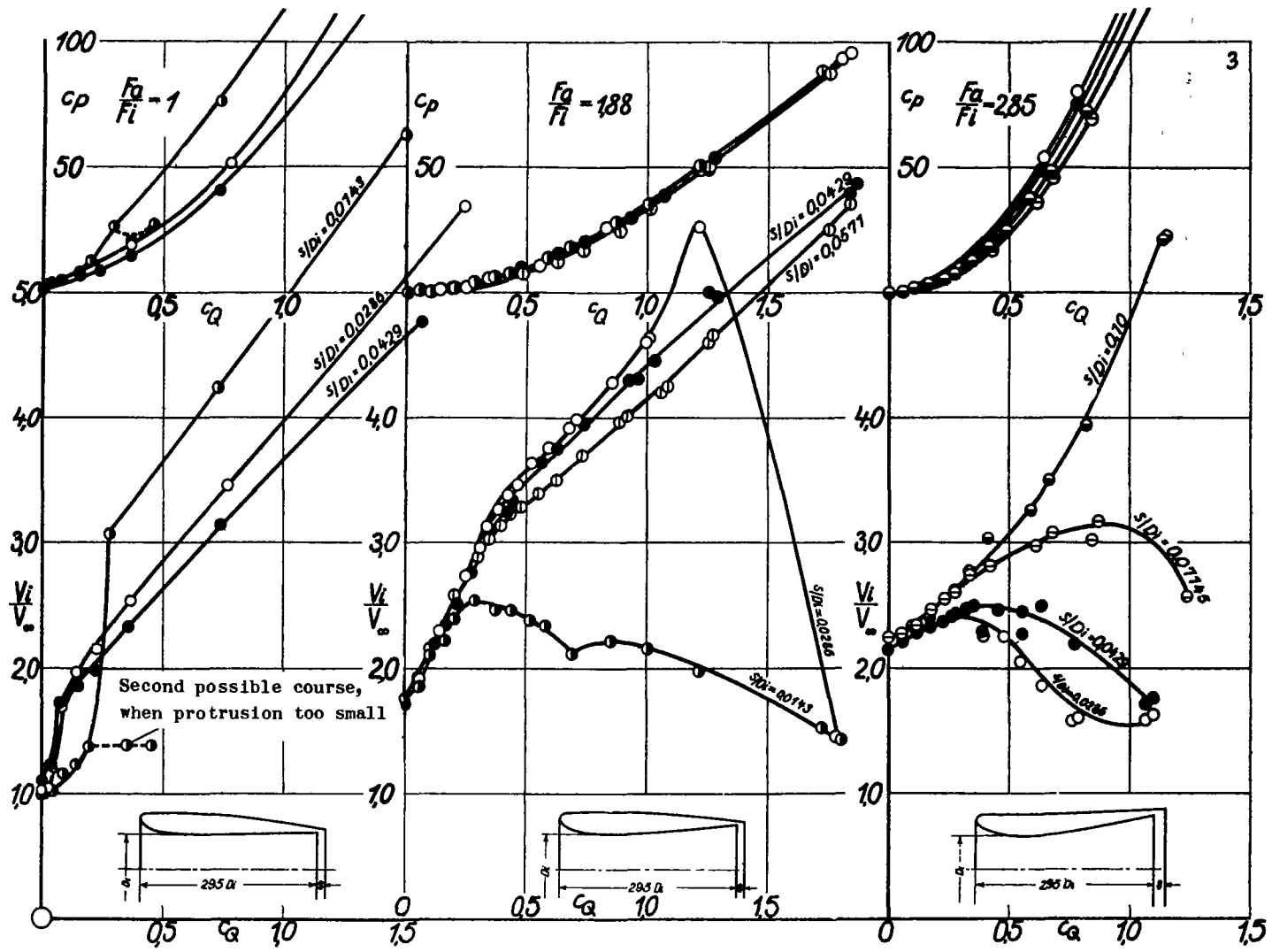


Figure 3 - Venturi tube with suction at the trailing edge.

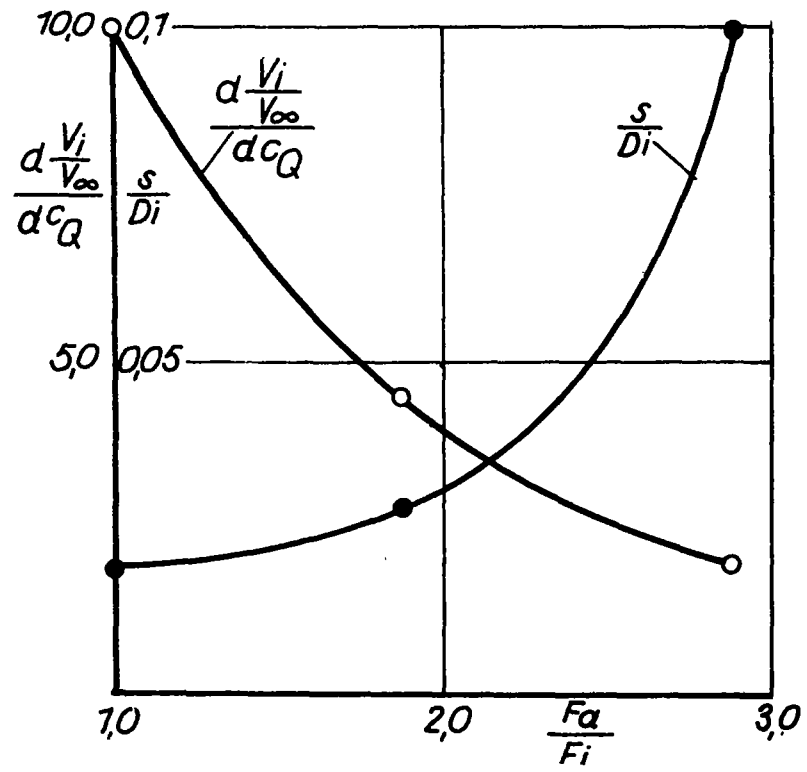


Figure 4.-  $\frac{d \frac{v_i}{v_\infty}}{d c_Q}$  = steepest increase in the region

$c_Q = 0.01 \div 0.3$ , and most favorable value

$\frac{s}{D_i}$  as a function of  $\frac{Fa}{Fi}$ .

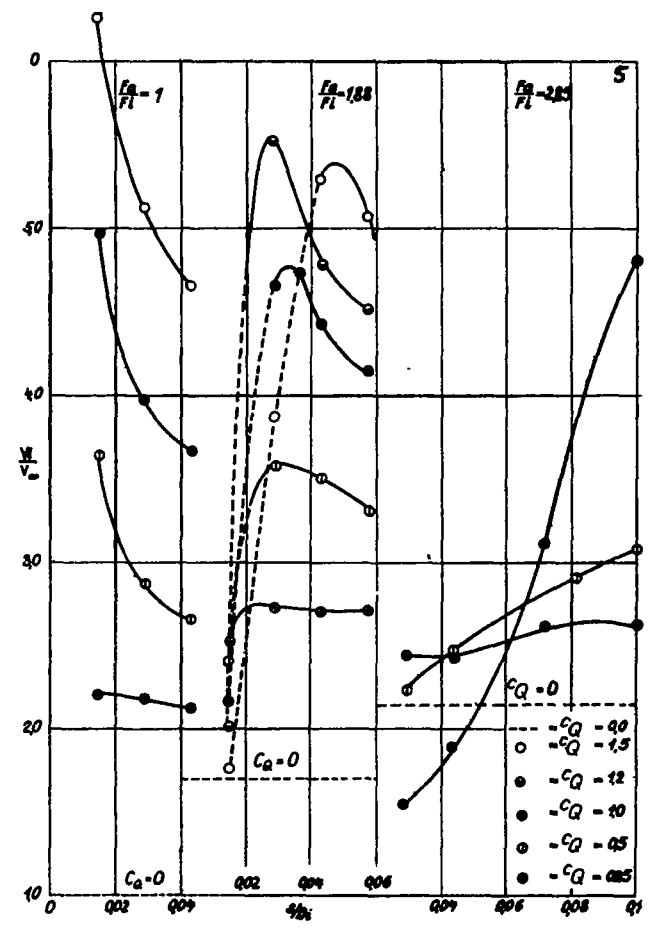


Figure 5.-  $\frac{v_i}{v_\infty}$  of the three tubes as a function of the protrusion  $s/D_i$  suction coefficients  $c_Q$ .

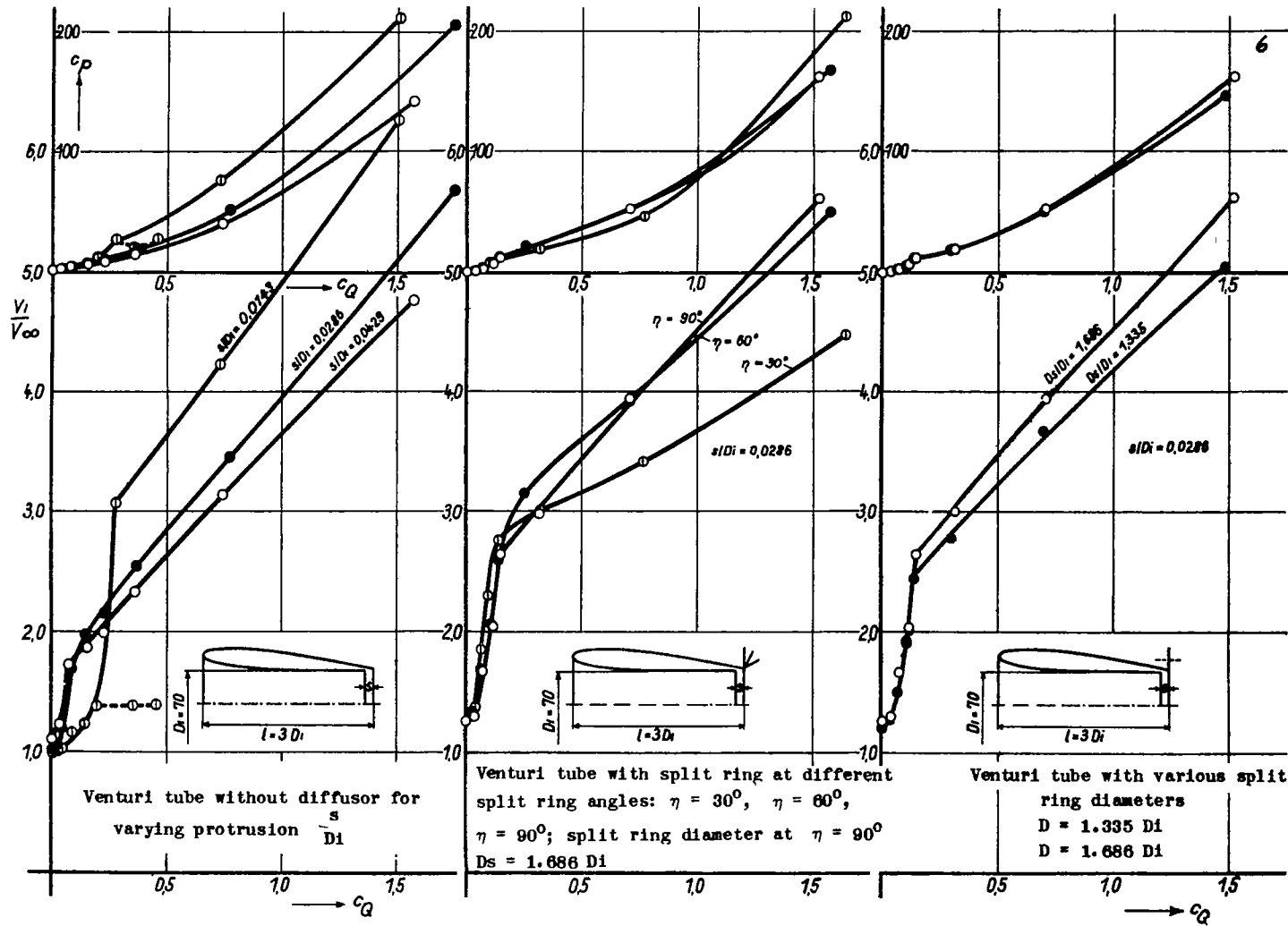


Figure 6.- Venturi tube with various flows. Influence of a split flap, of the split flap angles and the split flap chord upon the flow through the tube.



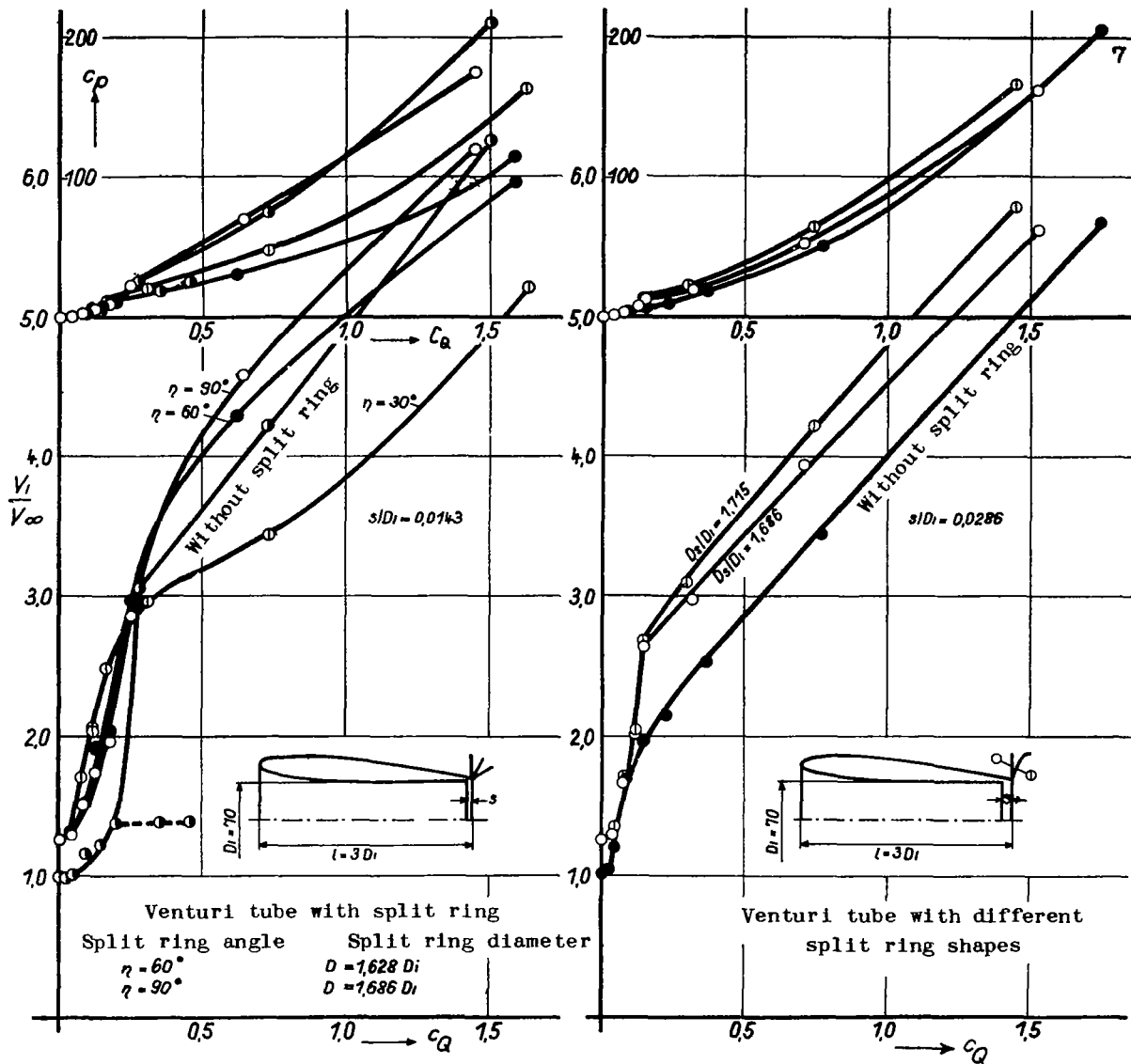


Figure 7.- Venturi tube with various flows. Influence of the split ring angle and the shape of the split ring.

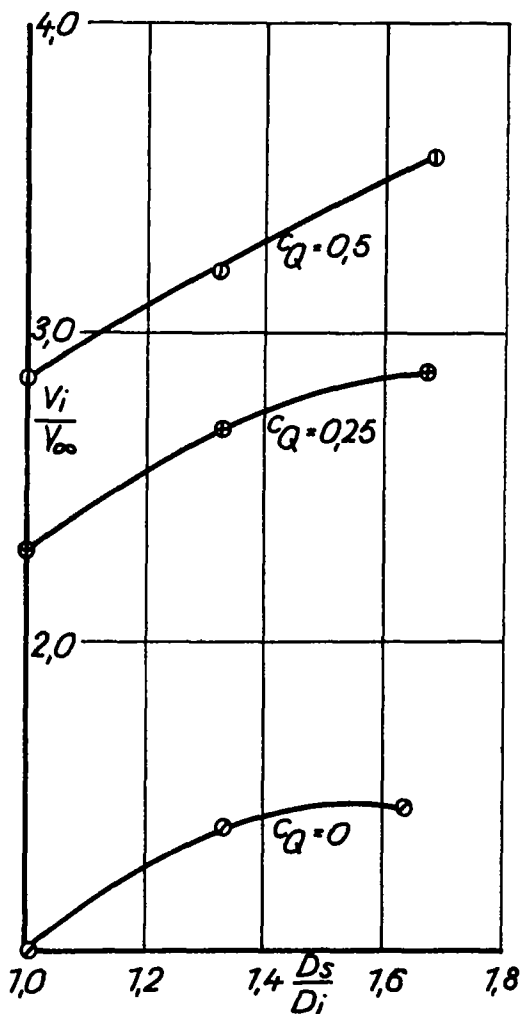


Figure 8.- Increase of the value  $\frac{v_i}{v_\infty}$  by the split ring for a given  $c_Q$ .

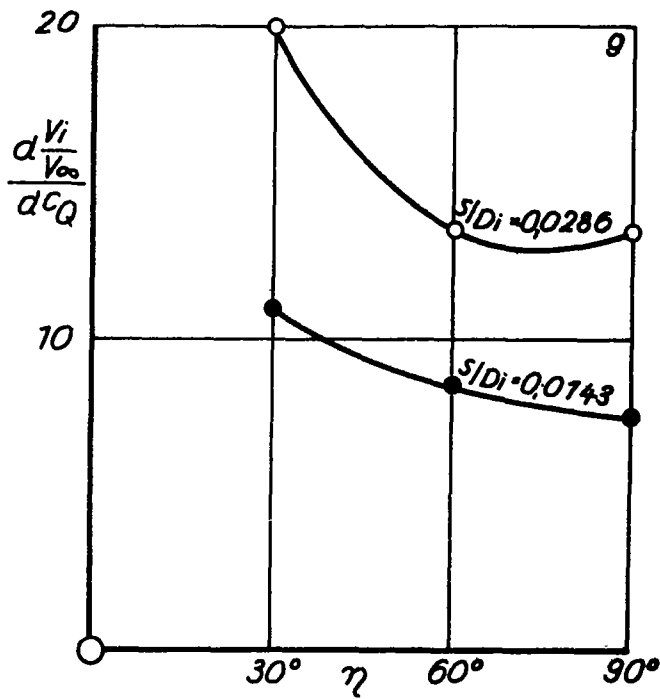
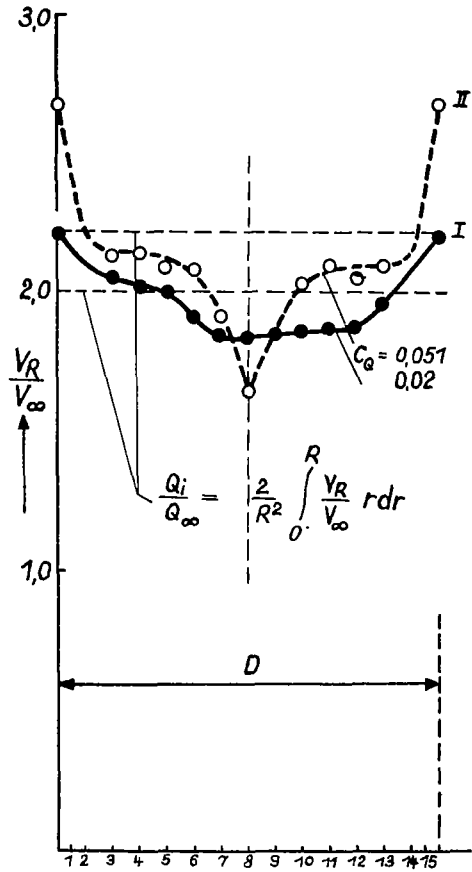
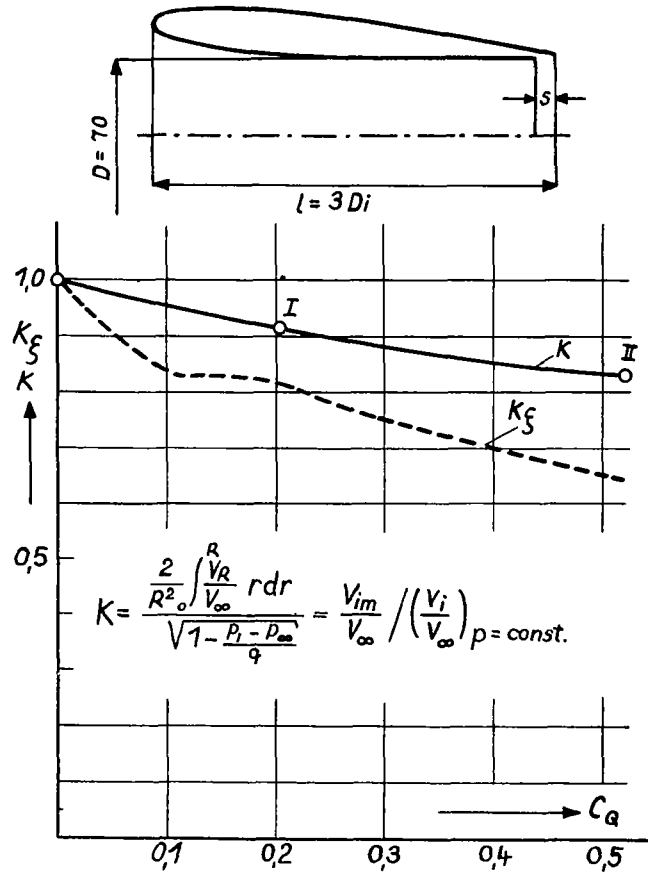


Figure 9.- Influence of the split ring angle

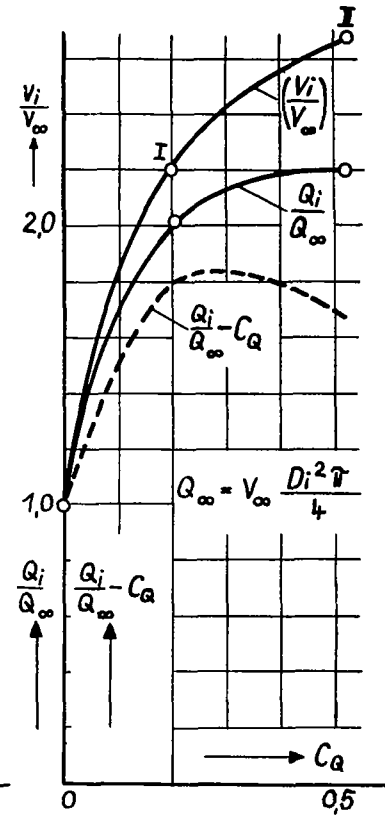
upon  $\frac{d \frac{v_i}{v_\infty}}{d c_Q}$  ( $c_Q$  - region of  $0.05 \div 0.15$ ).



Velocity distribution over the cross section of the tube.



Comparison of the real flow quantity with the calculated value. The calculation was performed under the assumption  $p = \text{const.}$  over the cross section of the tube.



Increase of the flow quantity by suction with and without consideration of the suction mass.

Figure 10.- Measurements for determination of the actual mass flow.

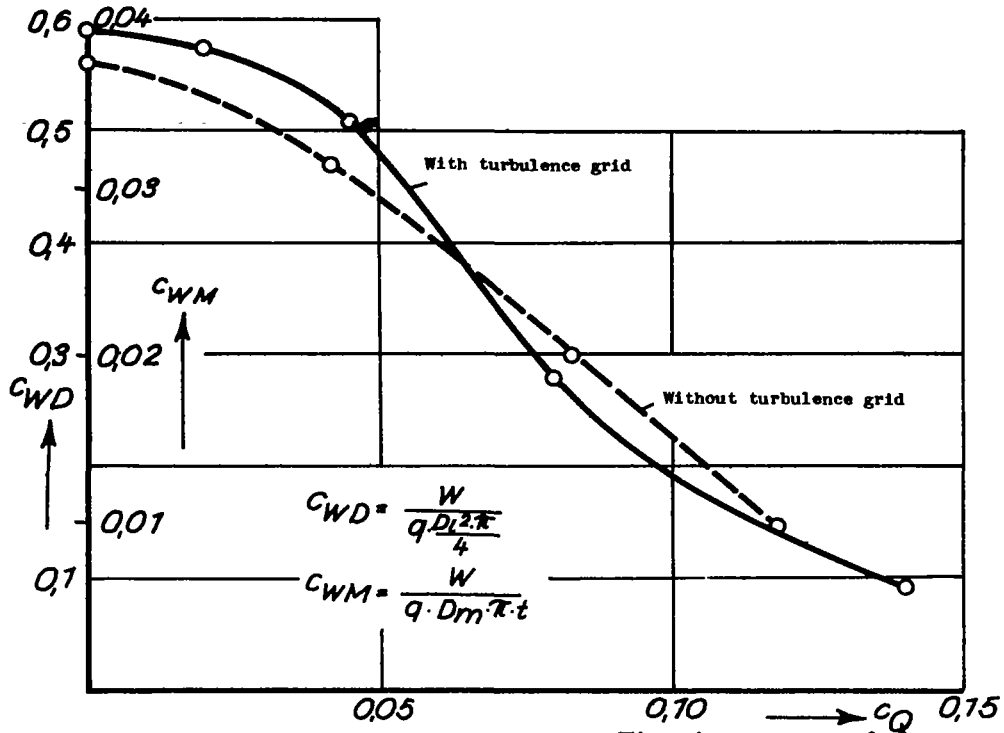


Figure 11.- Drag coefficient of the tube  $\frac{F_i}{F_a} = 1$  as a function of  $c_Q$  at  $\frac{s}{D_i} = 0.0286$ .

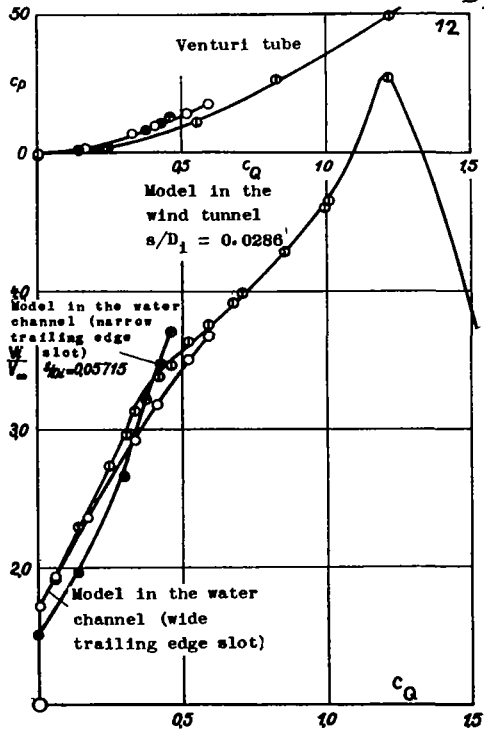
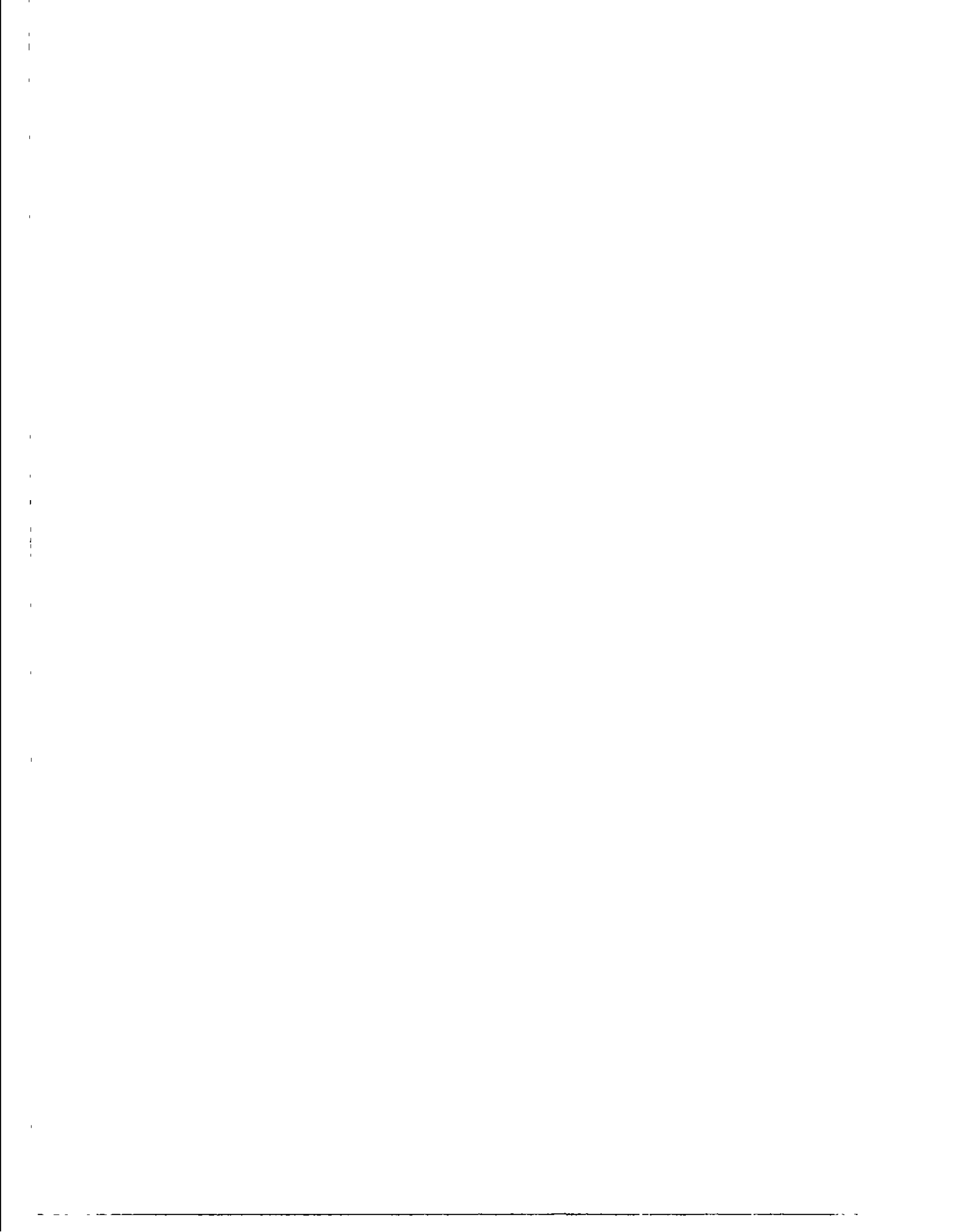
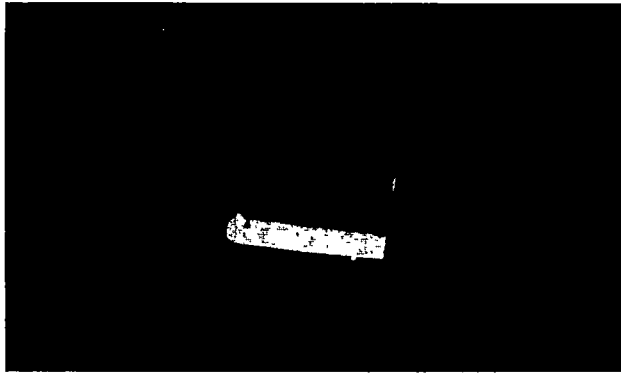
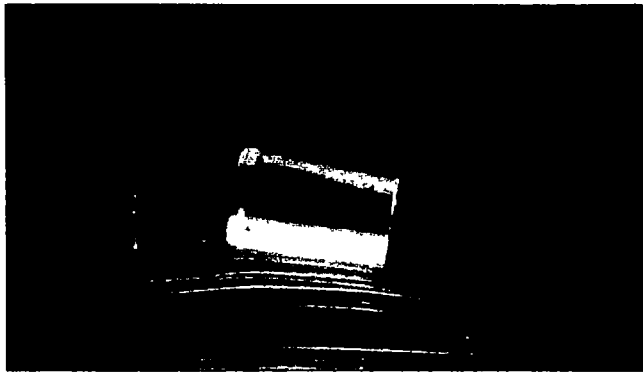


Figure 12.- Comparison of the test results in the water channel with the results obtained in the wind tunnel.





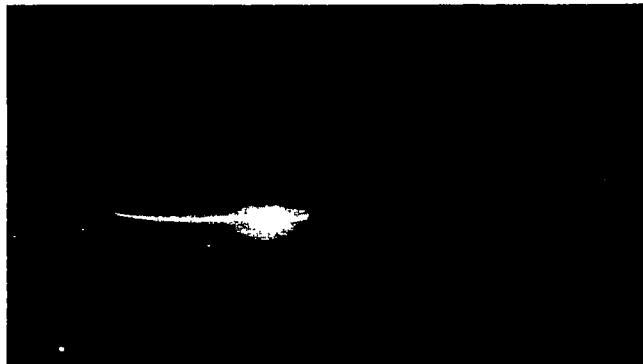
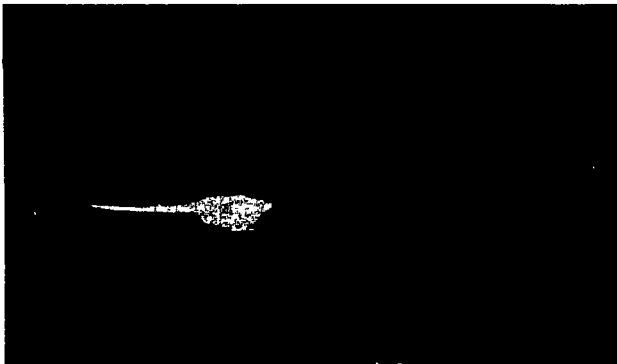
$C_Q = 0$



$C_Q = 2$

Figure 13.-

Flow through a  
Venturi tube  
with suction  
at the trailing  
edge.



For comparison  
wing flow with  
and without  
suction at the  
trailing edge.



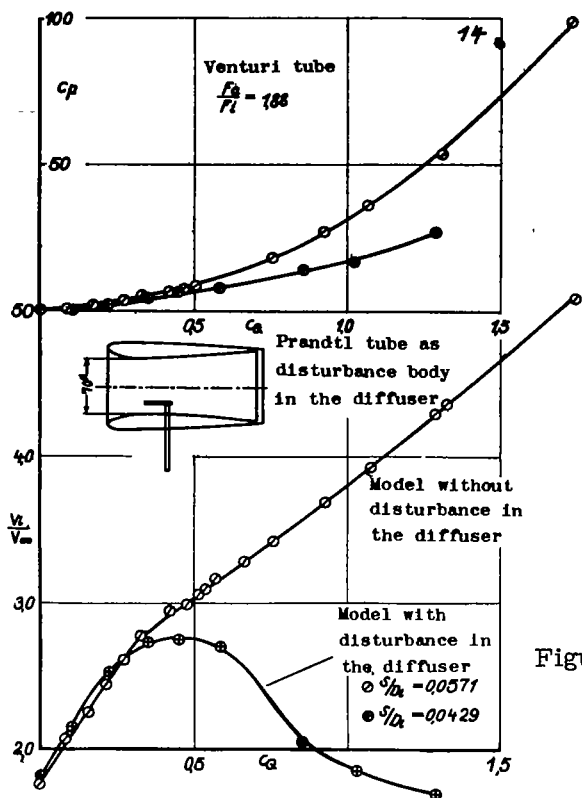


Figure 14.- Influence of a disturbance upon the course of the value  $\frac{v_1}{v_\infty}$ .

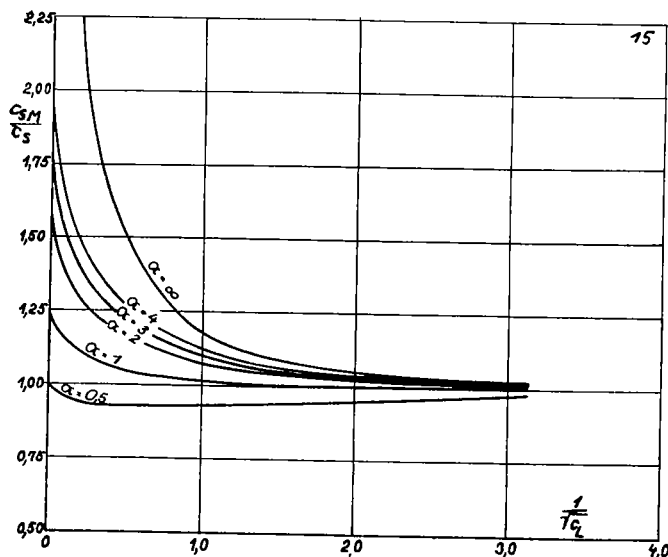


Figure 15.- Result of the momentum theory. The increase in thrust by a propeller shroud as a function of  $\frac{1}{\sqrt{c_L}}$  for various stream expansion ratios  $\alpha$ .



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