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THE DORNIER WIND TUNNEL

By H. Schlichting

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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL MEMORANDUM NO. 868

### THE DORNIER WIND TUNNEL\*

By H. Schlichting

#### SUMMARY

After completion of the required calibrations, the Dornier open-throat tunnel is now in operation. With an elliptic test section of 3 by 4 m (9.84 by 13.12 ft.), its length is 7 m (22.97 ft.), its maximum horsepower 800, and its maximum air speed 60 m/s (134.2 m.p.h.). As to local uniformity of velocity, static pressure as well as jet direction, and turbulence factor, this tunnel is on a par with those of the good German and foreign research laboratories.

The present equipment includes two purely mechanical balances: one 3-component, and one 6-component balance.

#### I. INTRODUCTION

The increasing demands for performance and airplane characteristics within the past few years have made the need for our own wind tunnel imperative. In the development of new design types, individual questions very frequently arise, in which small-scale investigations are of value in the construction only when they can be made within a definite - usually very short - period of time. Besides, much greater use is to be expected of the costly flight tests if they can be carried out in close cooperation with the wind-tunnel tests.

The Dornier Works have therefore built their own tunnel on their grounds at Manzell, near Friedrichshafen, and started to operate it (fig. 1).

Dimensions of the tunnel were decided on the basis of the following considerations: It was to be possible to

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\*"Der Windkanal der Dornier-Werke." Luftfahrtforschung, vol. 15, no. 3, March 20, 1938, pp. 95-100.

study complete models at a Reynolds Number sufficiently far above the critical Reynolds Number, namely:

$$Re = \frac{vt}{\nu} = 10^6$$

( $t$  is the wing chord,  $v$ , the air speed, and  $\nu$ , the kinematic viscosity of the air). Further, measurements on separate airplane components, such as radiators and engine nacelles at full size were to be possible. On the other hand, the costs and the time factor for wind-tunnel operation increase enormously with the size of the tunnel. For these reasons, the choice fell to an elliptic test section of 3 by 4 m (9.84 by 13.12 ft.) that can be enlarged to a 4 m (13.12 ft.) circular section by means of an interchangeable cone. The maximum jet velocity with the elliptical cone in normal operation is 52 m/s (116.3 m.p.h.), and can be raised to 60 m/s (134.2 m.p.h.) for short periods. The Reynolds Number for a normal wing (span 2 m (6.56 ft.), and chord 40 cm (1.31 ft.)) is:

$$Re = \frac{vt}{\nu} = 1.4 \times 10^6$$

## II. DESCRIPTION OF THE TUNNEL

The general design of the tunnel (figs. 2 and 3) follows the well-known Göttingen type, of which a number have been built in Germany, England, and the United States. It is an open-throat tunnel with single return. The air passages are in a vertical plane, the return being located beneath the test section. The length of the test section between entrance and exit cones is approximately 7 m (22.97 ft.); the entrance cone cross section is a horizontal ellipse of 3 by 4 m (9.84 by 13.12 ft.). The blower is mounted opposite the exit cone in the return passage and is driven through a 9.5 m (31.17 ft.) long shaft by a direct-current motor installed outside of the tunnel.

The tunnel building stands on a sloping piece of ground. This, with the vertical construction, made possible a very practical arrangement: the tunnel axis lies in the direction of the slope of the ground. On the uphill side the return passage lies 10 m (32.8 ft.) deep in the ground; on the downhill side, where the blower is mounted, it is almost level with ground, so that the power room has full daylight (fig. 2).

The horsepower required for the tunnel at maximum normal output is 420 kw., and 600 kw. for short periods. Wind velocities of 52 and 60 m/s (116.3 and 134.2 m.p.h.), respectively, are therewith attained.

The tunnel is almost completely housed within a 4-story building (fig. 1), which contains workshops on two floors and the offices on the top floor. The actual experiment chamber, through which the open jet passes, is three stories high. On the upper floor are the measuring platforms on both sides of a 6 by 20 m (19.68 by 65.60 ft.) opening and extending across the jet axis (fig. 8). Here a 3-component balance is installed on a platform which travels across the jet. A 6-component balance is to be constructed upon a second traveling platform. In this manner, one model may be prepared while the other is being tested.

The entire test chamber is within reach of a 1.5-ton (3,307-lb.) crane. The motor switchboard is duplicated: one in the engine room, the other on the platform near the balance.

### III. THE AIR PASSAGES

The greater part of the air passages are of reinforced concrete, but entrance cone, exit cone, and all deflector vanes are of sheet metal. The entire air passage rests on a base separate from the building.

The entrance cone (fig. 4) can be swung about a horizontal axis which is perpendicular to the jet axis, so that it can be adjusted to bring the jet axis in exact horizontal position. The exit cone mouth (fig. 5) is designed to fit the 3 by 4 m (9.84 by 13.12 ft.) elliptical, as well as the 4 m (13.12 ft.) circular cone. The entrance section of the mouth of the exit cone is elliptical, the exit section circular, and the adjoining return passage is of circular section. Thus the change from elliptical to circular jet takes place entirely within the exit-cone mouth. A circular slot between exit-cone mouth and the cone itself allows the air carried along from the test section in the open jet to escape. The throat is axially adjustable for about 600 mm (23.62 in.), so that the optimum slot width can be obtained. By changing the width of the slot the static pressure in the open jet near the exit-cone mouth is considerably influenced. The exit-cone pas-

sage following the mouth is expanded  $2^\circ$ , and the adjoining vertical passage is expanded  $4^\circ$ ; thus, part of the sectional expansion lies before the fan. The fan, of 5 m (16.4 ft.) diameter, is mounted in the return passage. Directly behind the fan, the 5 m circular section changes into a square section of 5 by 5 m. This is followed as far as the next bend (fig. 6) by the expanding passage terminating in a square section of 6.2 m (20.34 ft. square). From here on the section is constant as far as the mouth of the entrance cone. At the base of the entrance cone, the 6.2 m square section changes to a 5 m circular section, and in the attached steel entrance cone then ensues the further contraction from 5 m circular section to the elliptical jet mouth of 3 by 4 m or the 4 m circular jet. The area reduction for the elliptical jet is 4, and for the circular jet, 3. The jet is slightly expanded before the exit plane, in order to avoid contraction of the free jet shortly behind the mouth of the entrance cone. The deflectors on the last two bends before the entrance cone are rotatable as a whole about their longitudinal axis, but the remaining ones are fixed. This affords the correction for twist and velocity distribution in the open jet.

A honeycomb consisting of square cells 500 mm (19.69 in.) long, and 80 mm (3.15 in.) on a side, is mounted in the chamber near the base of the entrance cone.

#### IV. MOTIVE POWER

The fan is a 6-blade propeller of 5 m diameter (fig. 7), driven through a 9.5 m (31.16 ft.) long shaft from a direct-current motor outside of the tunnel. The motor is installed outside the tunnel for ease of accessibility. The direct-current drive motor is preferred to an alternating-current motor because of the ease of controlling the jet velocity. The current is transformed by grid-controlled mercury-vapor rectifier. The maximum normal output is 420 kw. at 400 r.p.m., and 600 kw. at 450 r.p.m. for short-period overload. The low peripheral speed not exceeding 118 m/s (264 m.p.h.) was chosen with a view to minimum noise. The hub part of the fan has a 2 m (6.56 ft.) diameter and is faired in. The hub is of welded sheet iron, the hollow blades are of cast elektron and are adjustable. The fan shaft rests on four bearings, two within the hub part, one intermediate, and one on the coupling to the

motor. Behind the fan are the 9-blade fixed contra vanes of 1.6 m (5.25 ft.) depth. The rear third of these vanes is pivotable with a view to correction of slipstream rotation. The hub part is carried on two front and three rear supports, the latter serving at the same time as contra vanes. The entire fan is housed in sheet iron, insulated from the rest of the return passage by partitions.

## V. SPEED CONTROL

Four valves in the lower side of the chamber in front of the entrance cone (fig. 2) keep the dynamic pressure in the open jet constant with respect to time. On opening of the valves, air escapes from the chamber, lowering the speed in the open jet. The valves are automatically controlled by an Askania air jet-tube controller. This type of regulator is superior to controlling the motor r.p.m., because it has less inertia for large wind tunnels. The regulator has a range from 40 to 120 mm (1.18 to 4.72 in.) W.S., and the set dynamic pressure is kept constant to within  $\pm 1/4$  mm (0.0098 in.) W.S. The dynamic pressure reading is obtained from the chamber in front of the entrance cone through an annular duct of 12 mm (0.472 in.) inside width fitted with 12 orifices.

## VI. MEASURING EQUIPMENT

This comprises at present a 3-component balance (fig. 8) mounted on a 5.6 by 4.6 m (18.37 by 15.09 ft.) traveling platform. The balance is completely mechanical and is patterned after the Gottingen 3-component balance (reference 1), but instead of scale beams with weights, sliding weights are used. The measuring range amounts to 100 kg (220.5 lb.) for the drag, 400 kg (881.8 lb.) for the lift, and the angle-of-attack range up to  $\pm 45^\circ$ . In addition, there is a fourth balance for the measurement of flap-hinge moments.

Provisions for a 6-component balance on a second traveling platform have been made; it is already under construction. It is also operated mechanically and is patterned after the Gottingen 6-component balance (reference 2), but the model can be turned through a full  $360^\circ$  about the normal axis. (Editor's note: In the meantime, the 6-component balance has been built and is in service.)

The models were made in the company's own shops, belonging to the wind tunnel. All complete airplane models are built with a span up to 2.8 m (9.19 ft.). The fabrication of the models followed closely the proved Göttingen method, namely: fuselage of wood, wings and control surfaces of iron coated with a 2 to 3 mm (0.079 to 0.118 in.) layer of gypsum. Notwithstanding the large size of the models, the wing frame (spars with ribs and sheet insertion) can be soldered. Deflection of the models under load was examined in preliminary tests; the results were satisfactory.

The models are suspended from round wires of 1 to 2 mm (0.03937 to 0.079 in.) diameter; very large models on streamline wires. Figure 4 shows a model suspended in the jet.

## VII. OPERATION AND JET CHARACTERISTICS

The actual construction of the tunnel was preceded by a searching test program on a model of the wind tunnel, 1:10 scale, in collaboration with the Göttingen Aerodynamic Laboratory. It included investigations of the dimensions of the air passages, the fan inclusive of guide apparatus with reference to satisfactory velocity distribution, and the behavior of the static pressure in the open jet. Performance tests were also made. Hereby it was found expedient to arrange the exit-cone mouth adjustable in axial direction, and to make the trailing edges of the contra vanes adjustable. Both were provided in the full-sized tunnel.

The operation of the tunnel has disclosed no particular difficulties. Oscillations of the air stream as observed on reversal of the newer tunnels, did not appear. The open-jet velocity in relation to the power input, computed on the basis of the model test, was exceeded by 15 percent. This is due to the fact that, at the Reynolds Number of the full size, which is ten times higher than on the model, the stream losses are considerably lower.

Following the starting of the tunnel, the open jet was tested very thoroughly. The measurements included:

1. Jet direction.
2. Velocity distribution.
3. Static pressure.
4. Turbulence factor.

Then the jet was alined exactly horizontally by means of a 3-component measurement on a normal airfoil. The jet characteristics were improved as much as possible by corresponding measures.

In the correction of the jet direction a maximum directional difference in the same horizontal or vertical section of  $0.2^\circ$  was aimed at and attained. The jet direction was measured with 2 m (6.56 ft.) long, thin silk threads, of which about five were arranged in vertical and horizontal planes, respectively. To improve the directional accuracy of the jet the best setting of the adjustable rear edges of the contra vanes was effected. A further improvement in jet direction was obtained by horizontal and vertical guide plates at the exit side of the honeycomb in the chamber in front of the entrance cone, which were twisted according to the existing directional differences.

The velocity distribution over the open-jet section, originally showing  $\pm 4$  percent dynamic pressure differences, was improved by "retouching" with the help of screens on the entrance side of the honeycomb. The maximum dynamic pressure difference has been reduced to  $\pm 1$  percent of the mean dynamic pressure (fig. 9), which is the usual figure for good wind tunnels.

The static pressure in the open jet shall axially be constant over the greater part of the open-jet length, in order to insure satisfactory drag measurements on very long models (airplane fuselage, for instance). The static pressure correction for the region before the exit-cone mouth was effected by changing the width of the slot between cone and mouth. The originally provided axial movement of the mouth made the variation of slot width easy. Ultimately the slot was set for 200 mm (7.87 in.) width.

The static pressure in the region directly behind the entrance-cone mouth was improved by changing the expansion angle of the cone with the aid of insertions. The final static pressure obtained is illustrated in figure 10. According to it the difference in static pressure for a test length of 5.5 m (18.04 ft.) is only 0.4 percent of the dynamic pressure.

To assure satisfactory 3- and 6-component measurements the jet must further be very exactly alined horizontally. A minor inclination  $\chi$  of the jet axis to the horizontal,

falsifies the drag  $W$  in a 3- or 6-component test by a lift component  $A \sin \chi$ , or a percentage of error in drag amounting to  $\frac{\Delta W}{W} = \frac{A}{W} \sin \chi$ . It is greatest in the range of best  $L/D$ ; and for  $\frac{A}{W} = 15$  and a jet inclination of  $\chi = \frac{1^\circ}{2}$ , it amounts to  $\frac{\Delta W}{W} = 13$  percent. To assure the drag measurement to be within 1 percent correct, the jet must not slope more than about  $0.03^\circ$ . Such an exact nozzle alinement being structurally impossible, it was attempted to achieve this by measuring in the usual manner (reference 3) the polar of a normal airfoil with "normal" and "inverted" suspension. The drag difference of the two polars then gives the jet inclination. In the present case the inclination of the nozzle to the horizontal amounted to about  $1/3^\circ$  upward, which was easily corrected since the nozzle had been initially mounted so that it could be rotated. Figure 11 shows the polars of the Gottingen airfoil section 409 after removal of jet inclination. The polars of the normal and inverted suspension coincide.

For comparison the Gottingen test of the same airfoil (reference 1, p. 107) in the 2.25 m (7.38 ft.) tunnel has been included. The Gottingen profile drag (at  $c_a = 0$ ) is greater and the maximum lift less than in our tests. Both are attributable to difference of Reynolds Number between the Gottingen and our measurement.

The turbulence factor of the tunnel was investigated after installation of the screens with the aid of the conventional sphere measurements. Polished wooden spheres of 200 and 300 mm (7.87 and 11.81 in.) diameter were employed. They were so suspended on the jet axis 1,600 mm (63 in.) away from the outside edge of the entrance cone, that no suspension wire was in front of the sphere. The results of the sphere-drag measurements are shown in figure 12. The critical Reynolds Number is  $R_k (c_w = 0.3) = 3.3 \times 10^5$ . Compared to the turbulence factors of other wind tunnels (reference 5), that of our tunnel can be called good.

Translation by J. Vanier,  
National Advisory Committee  
for Aeronautics,

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2. Ergb. Aero. Vers. Göttingen: IV. Lfg. (1932), p. 8.
3. Handbuch der Experimentalphysik, Bd. IV, pt. 2, p. 186.
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5. Platt, Robert B.: Turbulence Factors of N.A.C.A. Wind  
Tunnels as Determined by Sphere Tests. T.R. No.  
558, N.A.C.A., 1936.

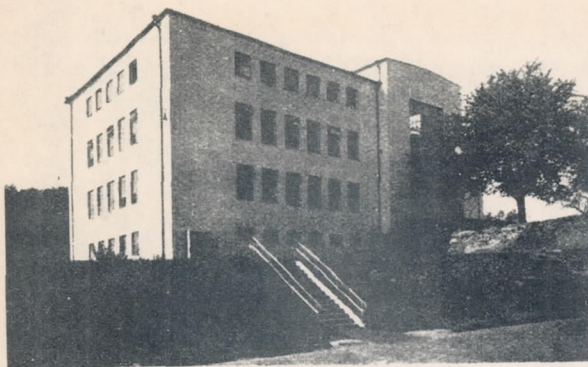


Figure 1.- View of wind tunnel building.

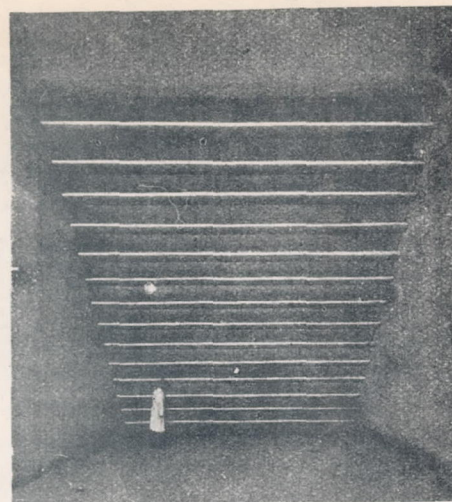


Figure 6.- The bend behind the fan  
(view in flow direction)

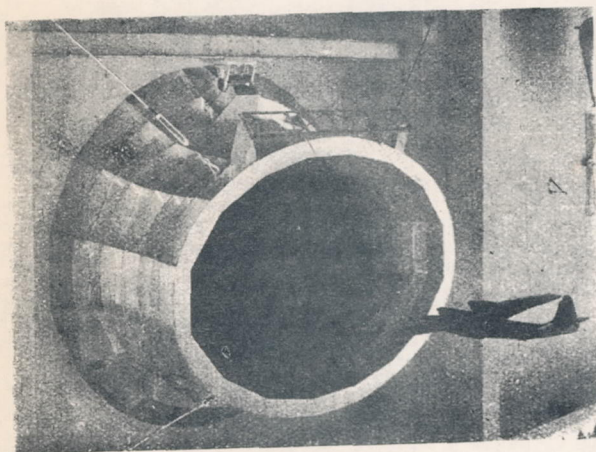


Figure 4.- View looking toward entrance  
cone and model.

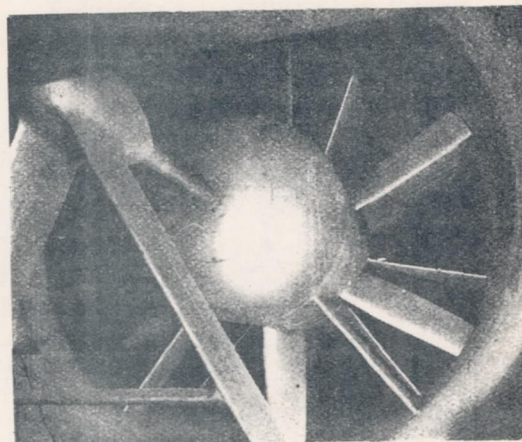


Figure 7.- Fan and contra vanes  
(view in flow direction)

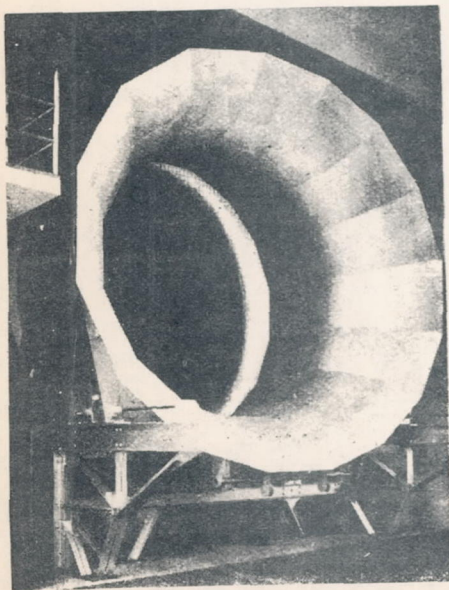


Figure 5.- View looking toward exit  
cone mouth.

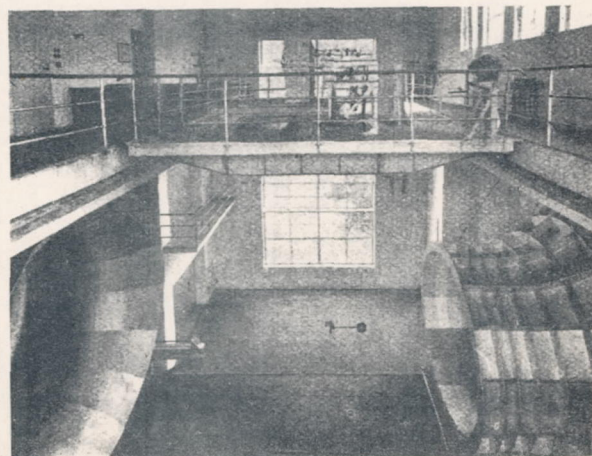


Figure 8.- Experiment chamber and  
3-component balance on  
traveling platform.

- a, Entrance cone
- b, Adjusting device for horizontal alignment of entrance cone.
- c, Exit cone mouth.
- d, Adjusting device for axial shifting of exit cone mouth.
- e, Deflectors or guide vanes.
- f, Fan blades.
- g, Contra-vanes.
- h, Hub fairing.
- i, Support of fan.
- k, Honey comb.
- l, Flaps for speed control.
- m, Askania controller
- n, Traveling platform for the balance
- o, 3-component balance.
- p, Electric drive motor.
- q, Current transformer.  
(grid-controlled rectifier)
- r, Offices.
- s, Workshop.

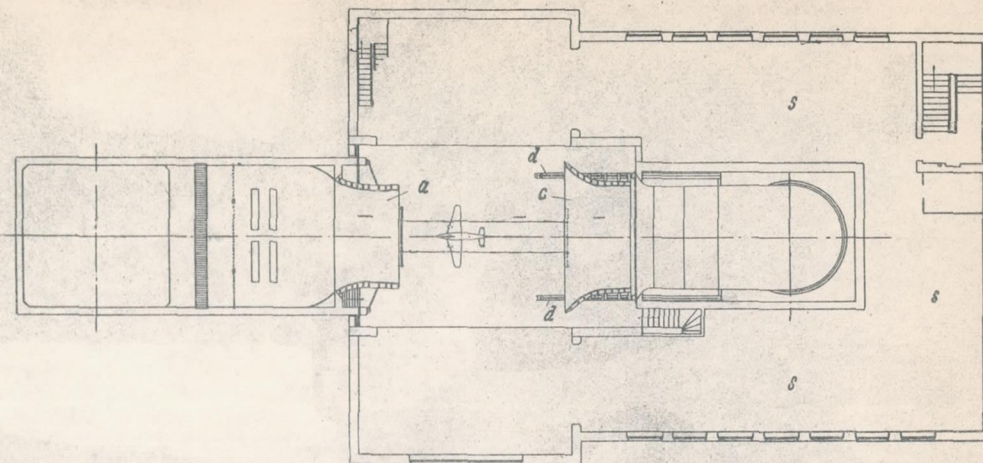


Figure 3.- Horizontal section of the wind tunnel.

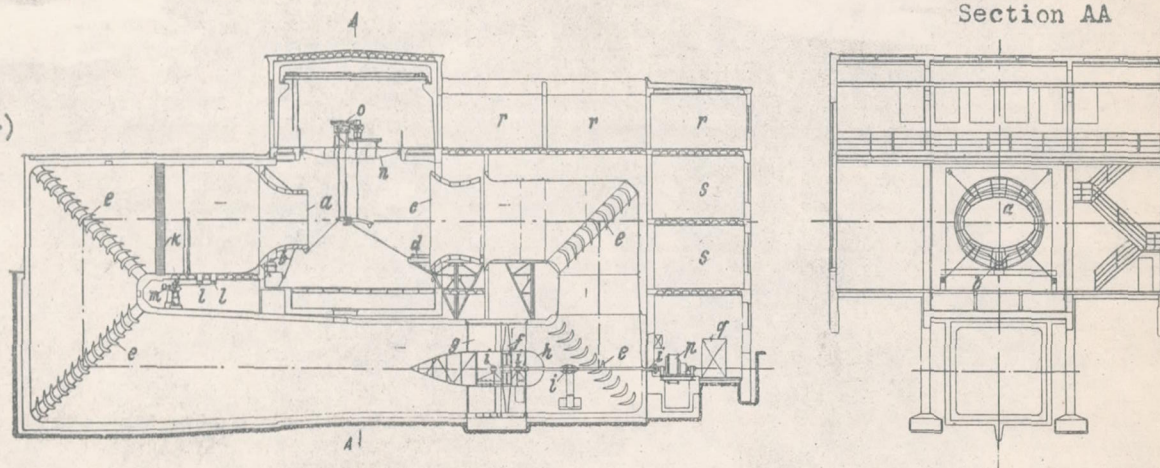


Figure 2.- Vertical sections of the wind tunnel.

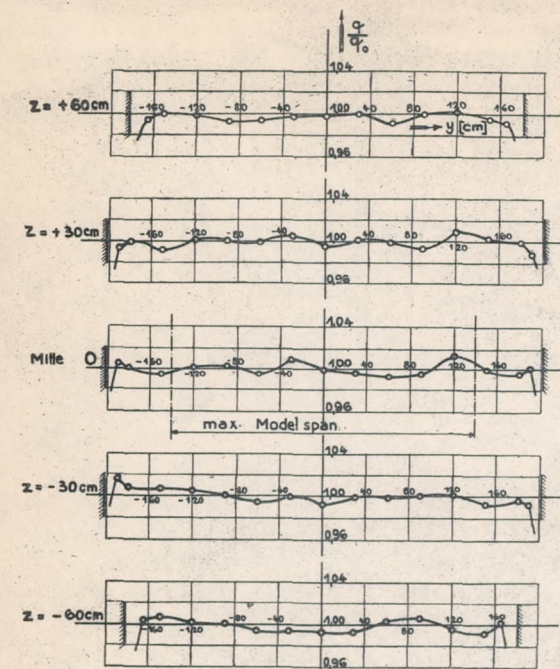


Figure 9.- Dynamic pressure distribution over 5 horizontal sections of the open jet 0.790 m away from the entrance cone.

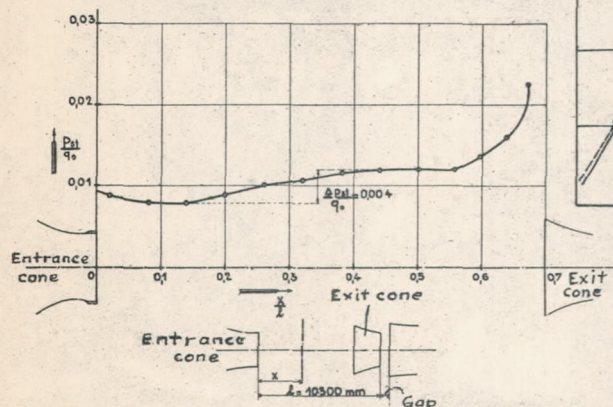


Figure 10.- Variation of static pressure on the jet axis.

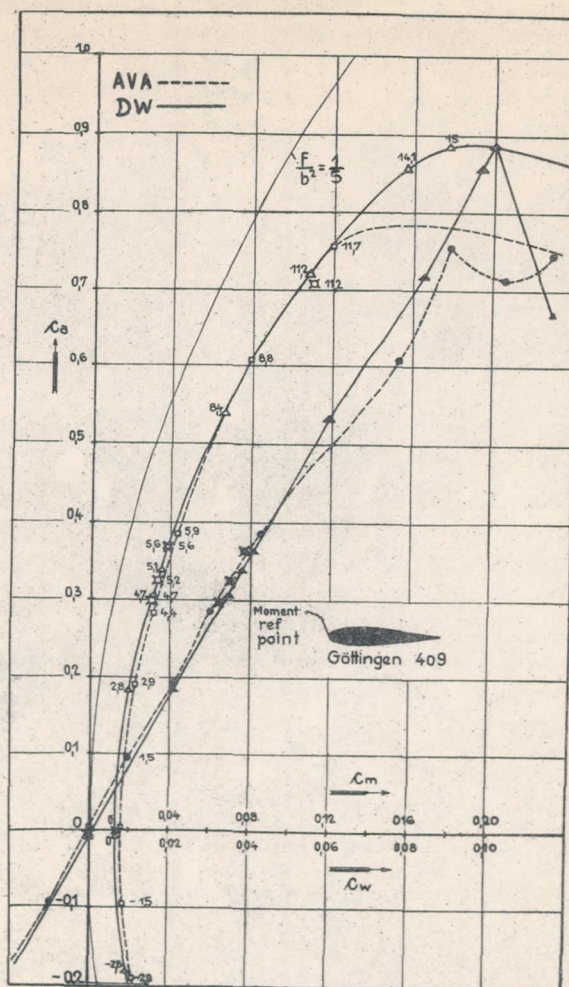


Figure 11.- 3 component measurement of a normal wing after horizontal alignment of the jet.

(airfoil section: Göttingen 409)

Span:  $b = 2.0$  m (6.56 ft.)

Wing area:  $F = 0.8$  m<sup>2</sup> (8.61 sq. ft.)

Wind velocity  $v = 30$  m/s (67 m.p.h.)

Comparison with Göttingen test according to reference 1, page 107.

Reynolds Number; Dornier  $\frac{vL}{\nu} = 8 \times 10^5$

" " : Göttingen  $= 4 \times 10^5$

1,  $c_a$  against  $c_w$ :

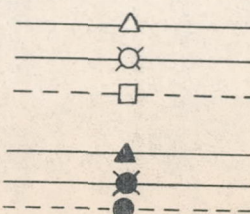
Dornier: normal suspension: ————  
inverted " : ————

AVA:

2,  $c_a$  against  $c_m$ :

Dornier: normal suspension: ————  
inverted " : ————

AVA:



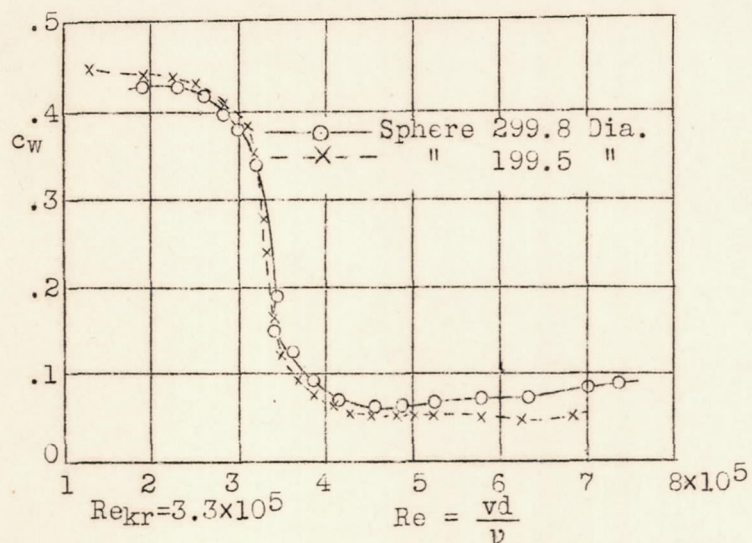


Figure 12.- Determination of turbulence factor from sphere drag measurements (200 and 300 mm (7.87 and 11.81 in.) diameter).

Critical Reynolds Number:  $Re_{kr} (c_w = 0.3) = 3.3 \times 10^5$