An Instrument for Drag Measurement in Flight.
Optimisation of Flap Settings

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An Instrument for Drag Measurement in Flight.
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Exact measurements in flight require a special instrumentation and are rather difficult. A simple and compact device is proposed for less pretentious results.

Rakes for drag measurement in the wake:

In principle drag is evaluated by integrating the loss of total head in the wake of the wing. This integration can be performed automatically by a so called "integrating rake" which consists of a number of equally spaced total head tubes aligned in a row perpendicular to the wing trailing edge /1/. The distance between the trailing edge and the openings of the rake tubes is usually about 0.3 * wing chord c. The rake has to extend over the whole wake. All its tubes must have the same length and a diameter that causes laminar flow with its average velocity being proportional to the difference of the pressures at both ends. All tubes are connected to a common chamber. The pressure in this common chamber represents the average of the pressure distribution over the wake. A rake for exact measurements of drag should be built up of tubes with 0.8 mm o.d. with length of 100 mm and a spacing of about one or two diameters. It should be 60 to 80 mm wide depending on airfoil chord. The cross section of the common chamber must be big enough to avoid a pressure gradient along its length. Rakes of this type are used in the Laminar Wind Tunnel of the Institute. The maximum total head loss and static pressure in the wake must be measured for use in formulas for corrections.

In principle the drag of that part of the wing that is located in the plane ahead of the rake is evaluated. The drag is normally constant along the span when no flaps or other disturbances are present. In some cases longitudinal vortices exist in the boundary layer /2/ and cause periodical variations of the drag in spanwise direction (fig.1). This phenomenon demands special attention as integration of the drag along the span. When measuring c_d in the LWT the rake is traversed in spanwise direction at a constant angle of attack and the drag coefficients are integrated.

A rake of simpler construction:

Under crude conditions a simpler rake which is less susceptible to damage can be used. Its construction is sketched out in fig.2. It consists of a flat piece of aluminum alloy which holds the tubes of 1.4 mm o.d. and forms the plenum chamber. It is attached to the trailing edge of a flap in a distance of 0.1 * chord. The total length of the rake is reduced to 36 mm.

Wind tunnel tests: Drag measurements with this rake were compared with the drag measured by the normal rake installed in the LWT. Fig.3 shows polars for a flapped model gathered with the tunnel rake (without integration along the span) and polars with the test rake installed at the same spanwise position. The polars of both rakes show good agreement. In fig.4 the distance of the test rake was reduced to 0.05*c. In this case differences exist for the positive flap deflection of 15 degrees. The results achieved by this simple and robust rake are of sufficient accuracy for most cases. However, if drag information is required during normal flight activity, the additional drag, caused by the suspension of the rake behind the wing deteriorates the performance of the airplane and therefore can not be accepted.

A rake mounted at the wing trailing edge for use in normal flight activities:

A simple device for drag measurements was proposed by R.H.Johnson /3/. It merely consists of the flat piece of aluminum alloy as depicted in fig.2 without the protruding tubes. This device is fixed to the wing trailing edge by a slot halving its height. Thus it measures the total head losses in the wing boundary layers on its suction- and pressure-side. Fig.5 shows the distribution of the total head differences in the boundary layers for different distances from the wing surface at two different flight conditions. The device is intended to be used as a relative drag indicator and as a help for finding the best setting of the flap for the existing flight condition. As fig.6 indicates it yields an incorrect drag bucket for the different flap settings when compared to the tunnel rake. Thus it can not be used for optimisation of the flap setting.

As tests in the wind tunnel revealed the missing tubes cause wrong results because there are no defined stagnation points for the single bores so that they can not read the true pitot pressure. In addition this failure is caused by the fact, that the plenum chamber of the rake connects the pressure openings of the suction- and the pressure-side of the wing where different static pressures exist.
A rake integrating the pressures of both wing sides in two separate plenum chambers (fig.7) was designed in order to overcome this difficulty. These chambers are again connected to the output tube over throttle tubes with identical dimensions. So the pressures from both chambers are averaged for the output. As fig.8 shows, the drag buckets are correctly reproduced by this device. Absolute values were not calibrated because they are not of interest in this context. Fig.9 is a photograph of this rake. It has an additional tube for reading the undisturbed total head outside the boundary layer. The drag is proportional to the pressure difference between the undisturbed total head and the integrated pressure from the rake.

Construction of the rake (fig.7):

The body consists of aluminum with the dimensions of 62 mm x 20 mm and 3 mm thickness. It is symmetrical to its centre line. Some of the bores are shown with inserted tubes T1. They have an outer diameter of 1.4 mm and are 14 mm deep. They end in the common bores marked by (1) which represent the plenum chambers and have a diameter of 2 mm. The bores marked by (2) with 2 mm diameter are drilled through the whole rake. The two outmost measuring bores marked by (3) are 18 mm in depth and connect the bores (1) and (2). So the bore (2) connects the upper and lower halve of the rake. The two throttle tubes T2 with 1 mm o.d. and 2 mm o.d. and 20 mm long are inserted in bore (2). The bore (4) connects bore (2) with the output tube (5) which is glued to the rake body on both sides. One of its ends is sealed. All bores must be carefully cleaned. The openings of bores (1) (2) and (4) have to be sealed without clogging the bores for instance by covering with thin glas fibre with epoxy resin. The slot for the wing trailing edge must be adjusted to the wing. The measuring tubes are inserted in their bores so that they protude 6 mm and are fixed by adhesive. The rake must be thorougly tested for leakage. By this construction the total heads in the boundary layers of both sides of the wing are integrated seperately and these two pressures are averaged by the two throttle tubes T2. By means of this rather simple and rugged device, fixed to the wing trailing edge, the wing drag can be measured without introduction of too much additional disturbances and with simple installation.

Installation and instrumentation:

Some additional provisions are necessary however to gain reliable results /4/. The pneumatic system must be compensated so that a small change in pressure encountered simultaneously at the rake and at the port, where the total head is connected, is of no influence on the reading of the pressure sensor used. This can partly be achieved by taking the total head from an additional tube at the rake (fig. 9) connected by flexible tubing with the same length and diameter as the tubing for the rake pressure. An electric pressure sensor as used in variometers can be employed. A more comfortable instrumentation includes a second pressure sensor for the dynamic pressure and an analog device which divides the rake pressure difference by the dynamic pressure thus making the output more insensitive to variations of flight speed. By the use of two or more rakes at different postions drag values can be compared by scanning the pressures.

References:

/1/ Althaus, D. Widerstandsmessung mit integrierenden Rechen.
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/2/ Althaus, D. Drag Measurements on Airfoils.
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/3/ Johnson, R.H. At least:An instrument that reads drag.
Soaring October 1983

/4/ Althaus, D. Ein einfacher integrierender Rechen für Widerstandsmessungen an Tragflügeln.
Aero Kurier 1990/7

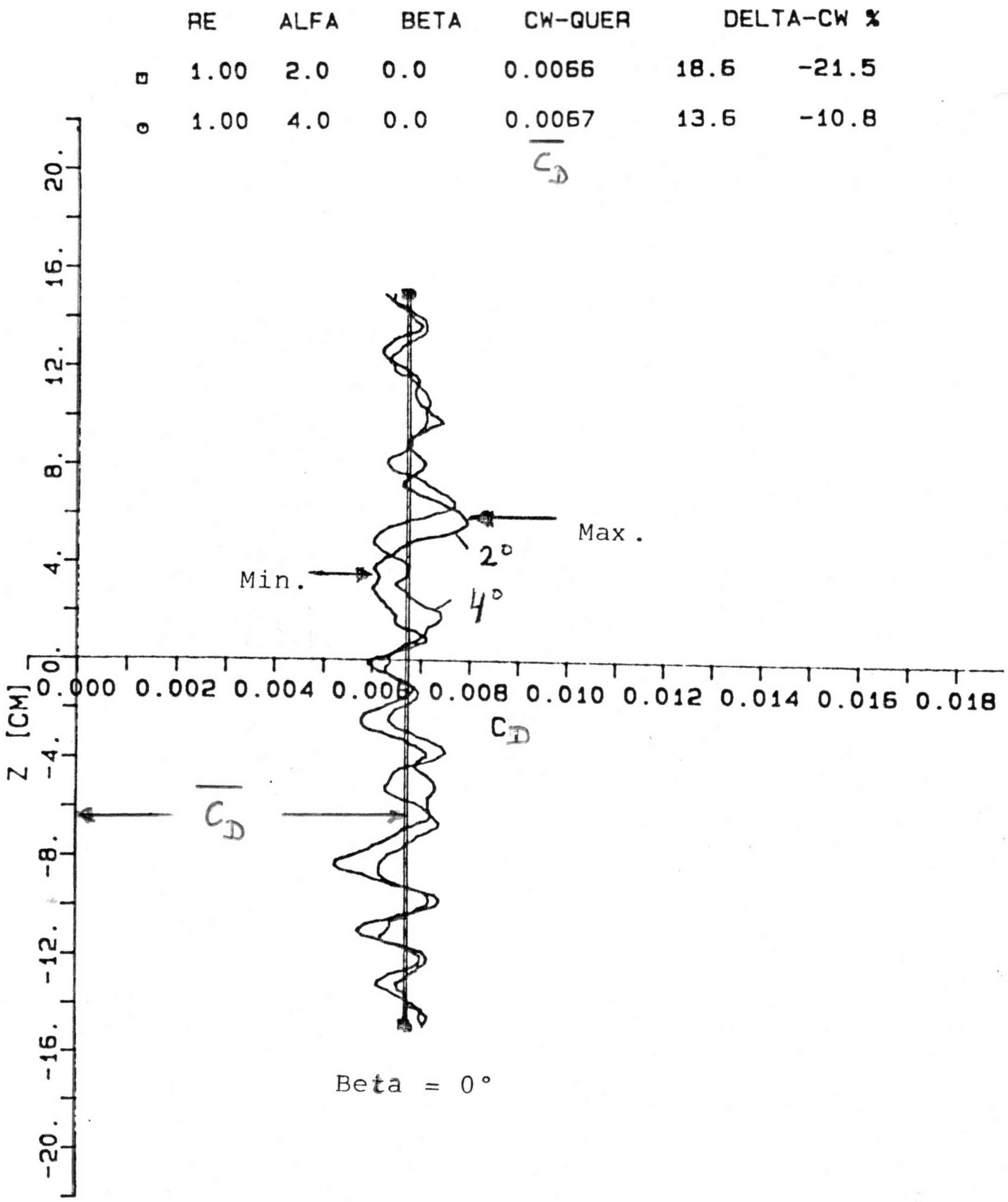


Fig. 1: Drag coefficients along span z showing longitudinal vortices.

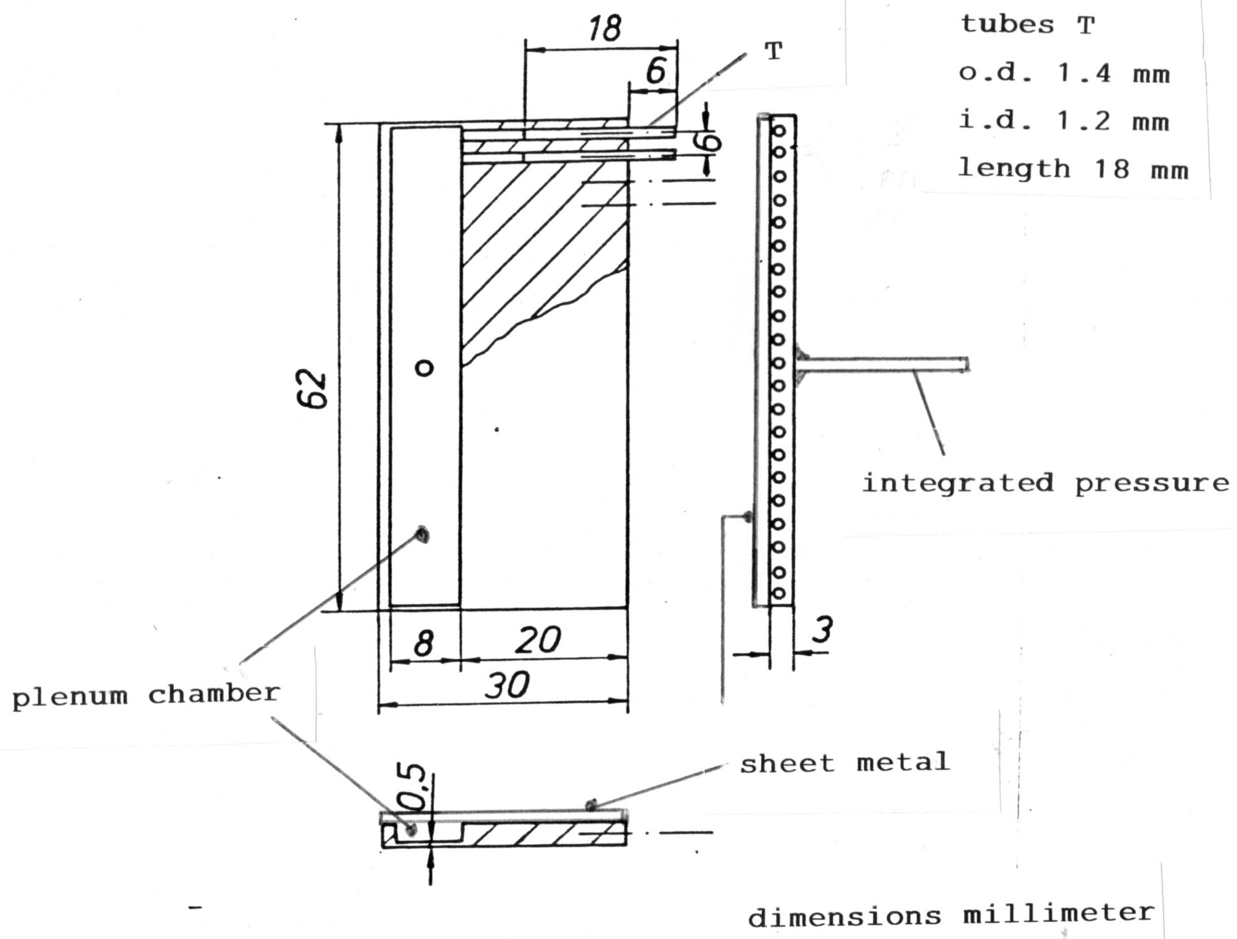
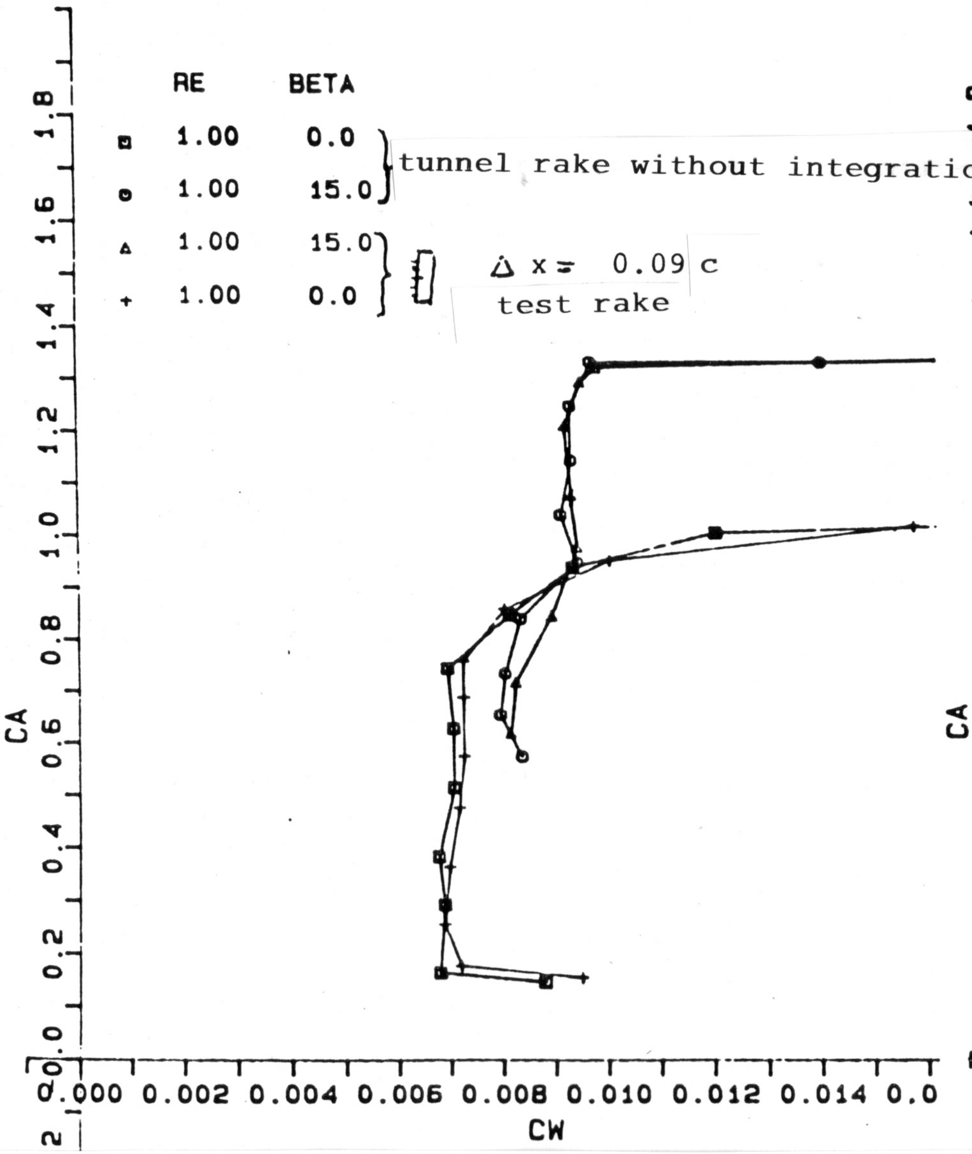
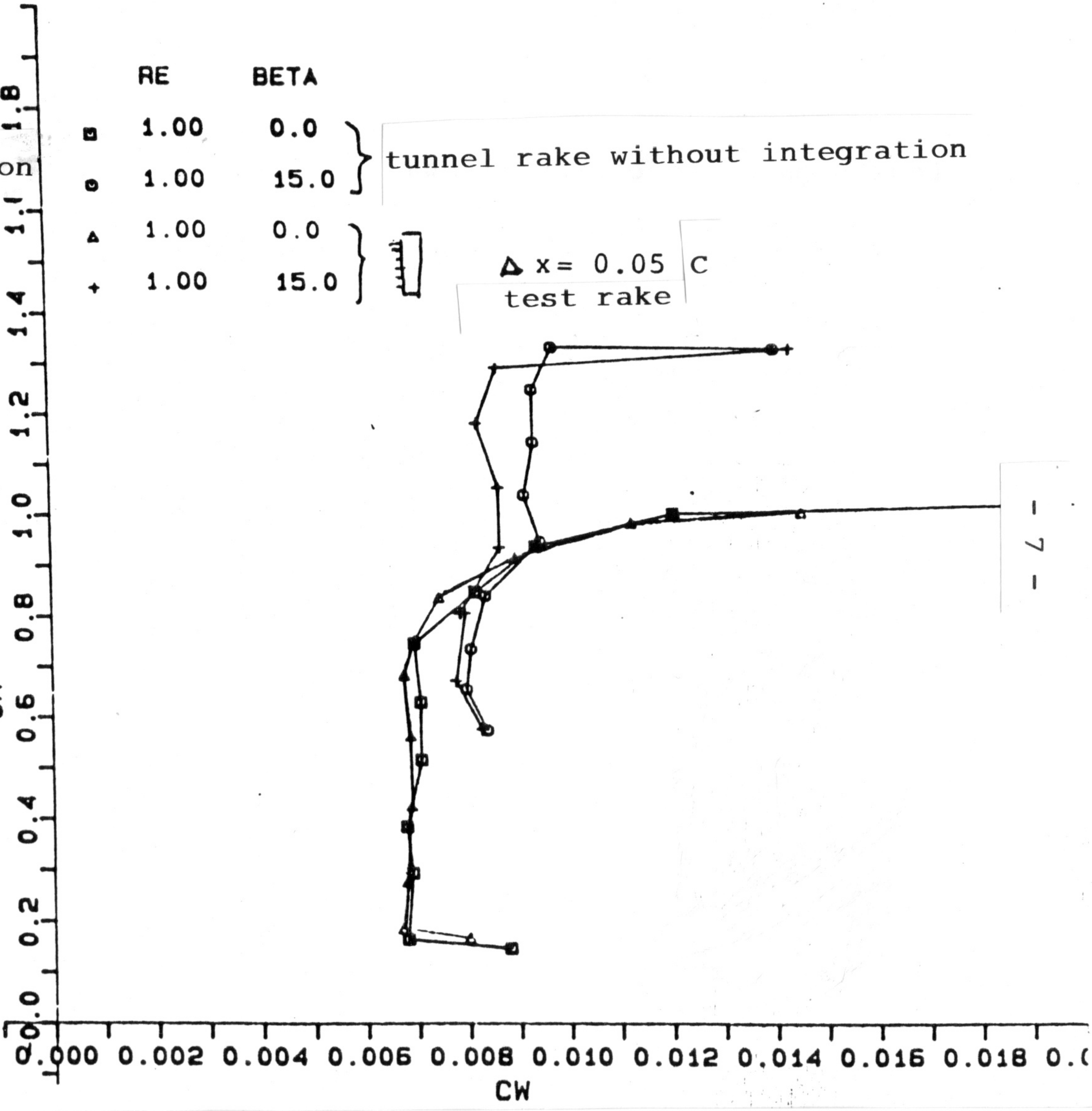


Fig. 2: Construction of a simple integrating rake for measurements in the wake.



Polars from test rake in comparison with polars from tunnel rake for flap deflection 0 and +15 degrees. Distance of test rake to trailing edge 0.09 c.

Fig. 3:



Polars from test rake in comparison with polars from tunnel rake for flap deflection 0 and +15 degrees. Distance of test rake to trailing edge 0.05 c.

Fig. 4:

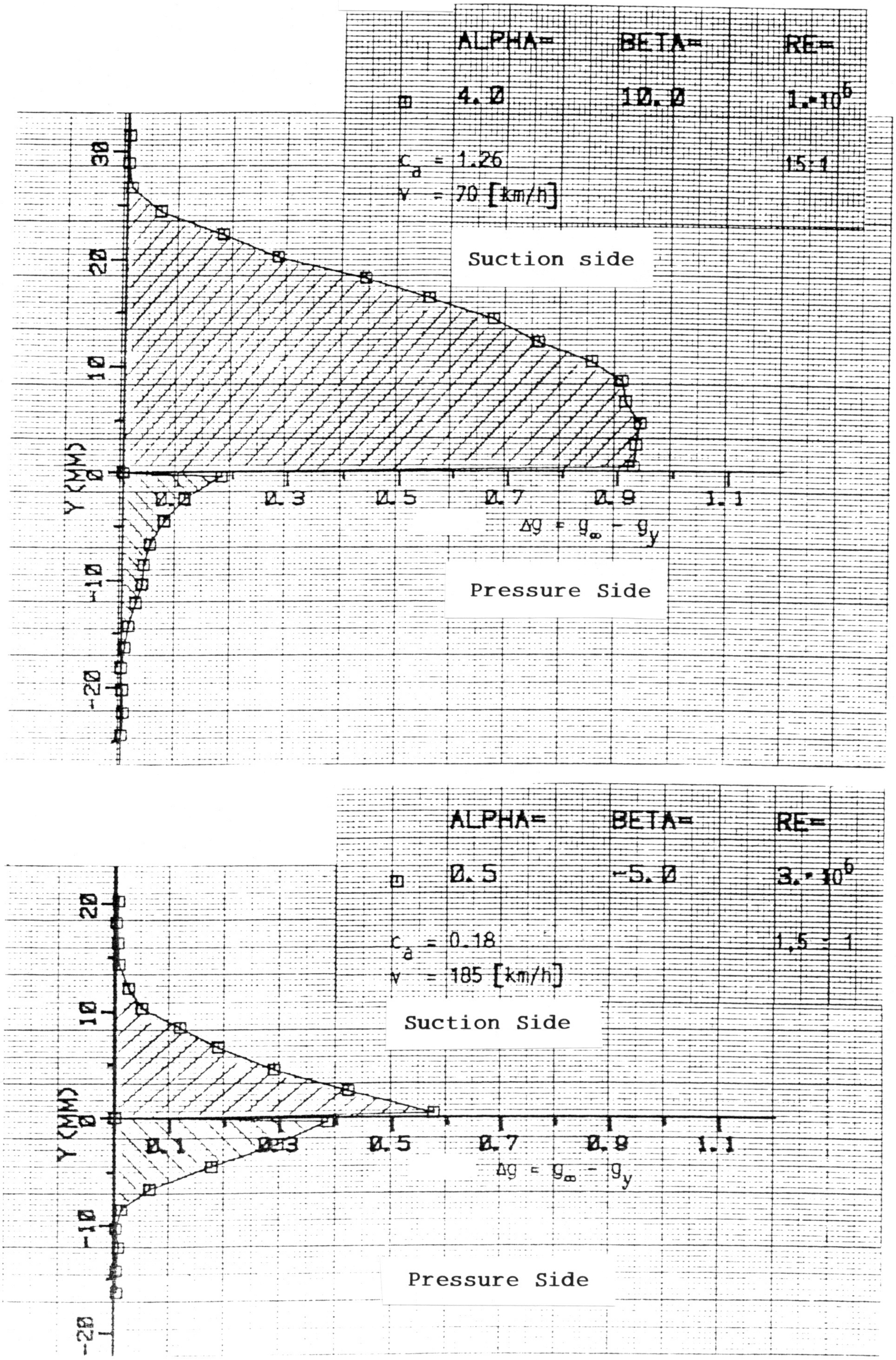


Fig. 5: Total head loss in the boundary layers at the trailing edge of an airfoil with 700 mm chord for two different flight conditions. y = distance from wing surface.

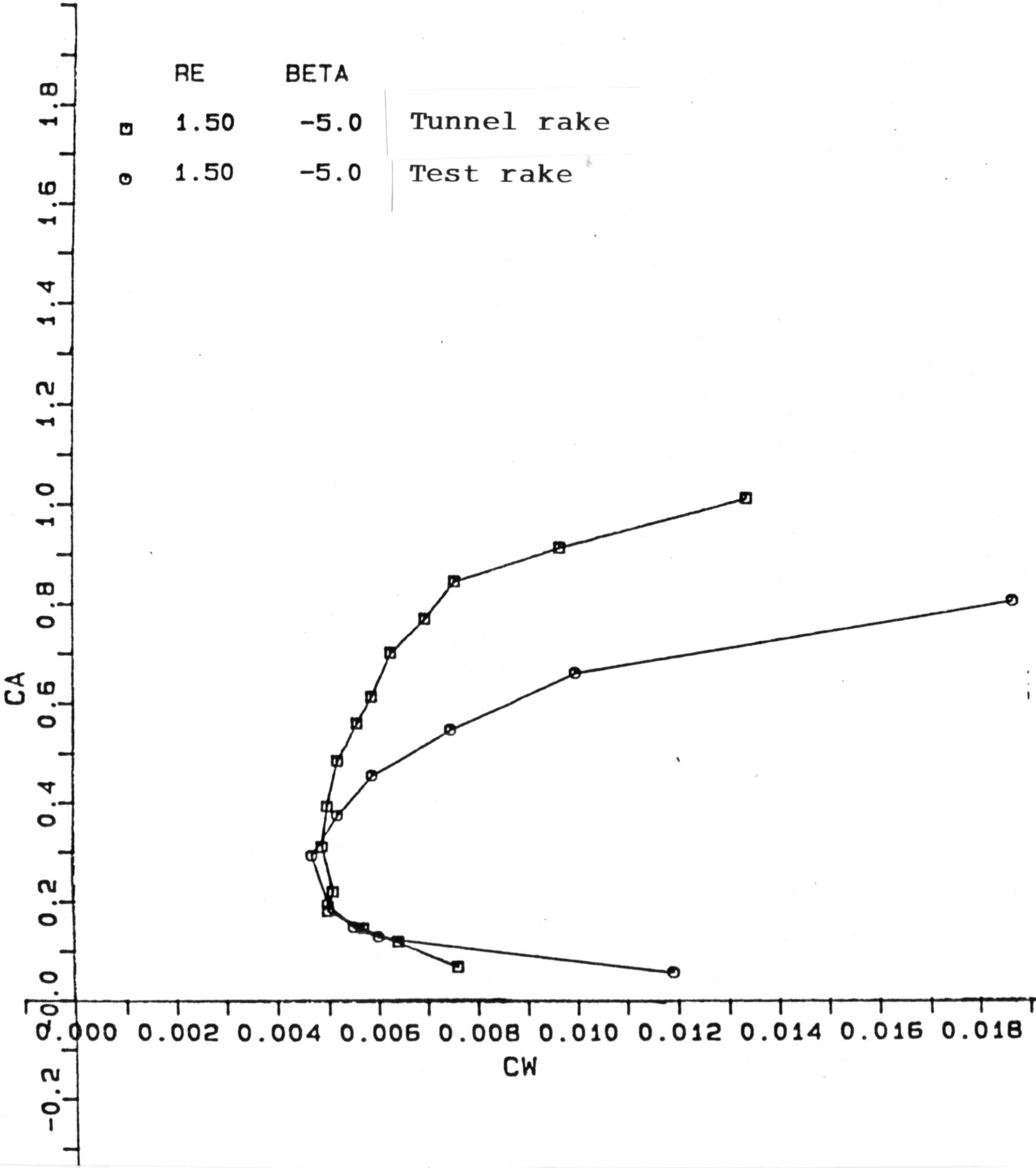


Fig. 6: Polar from rake due to Johnson /3/ in comparison with polar from tunnel rake.

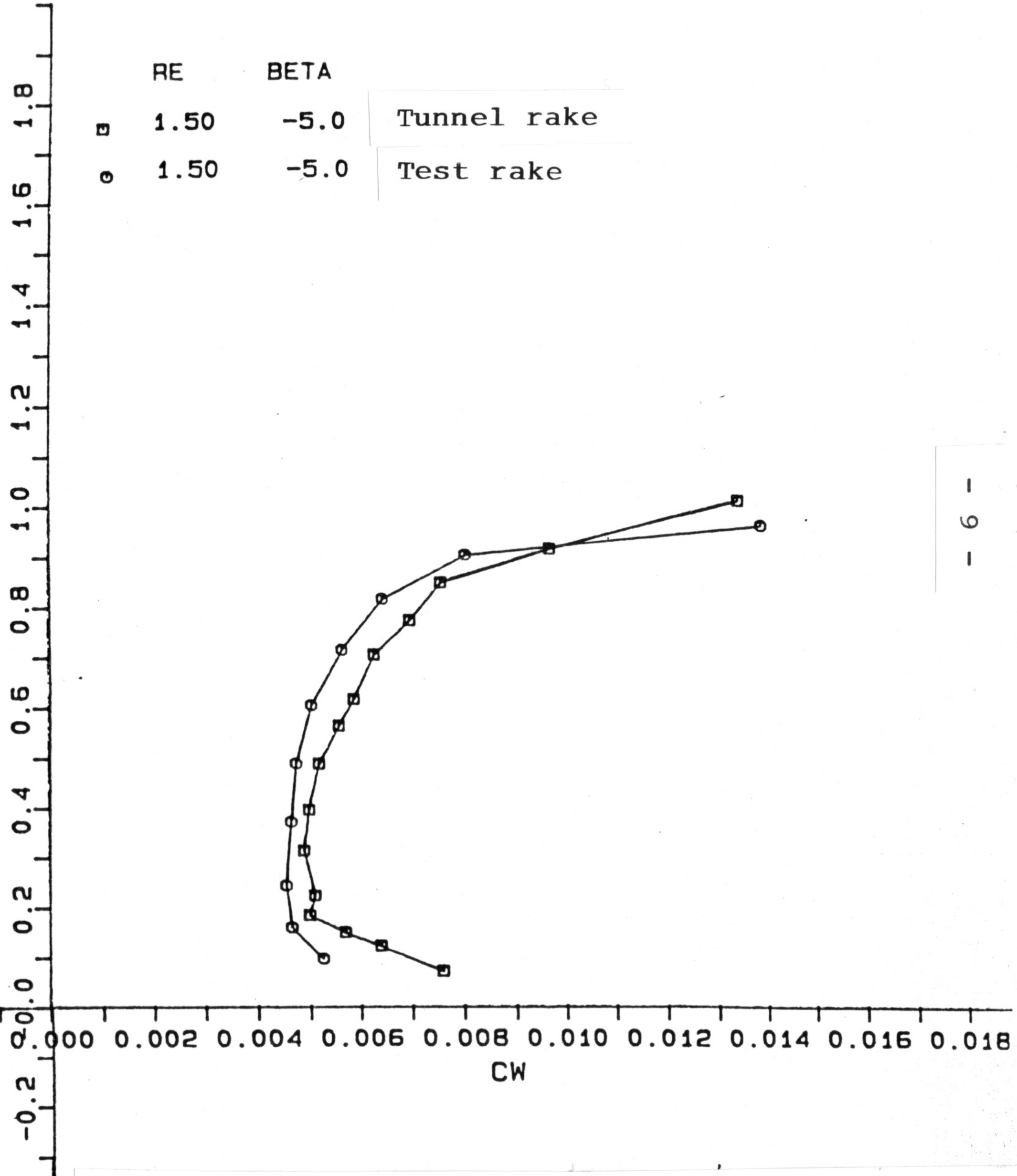
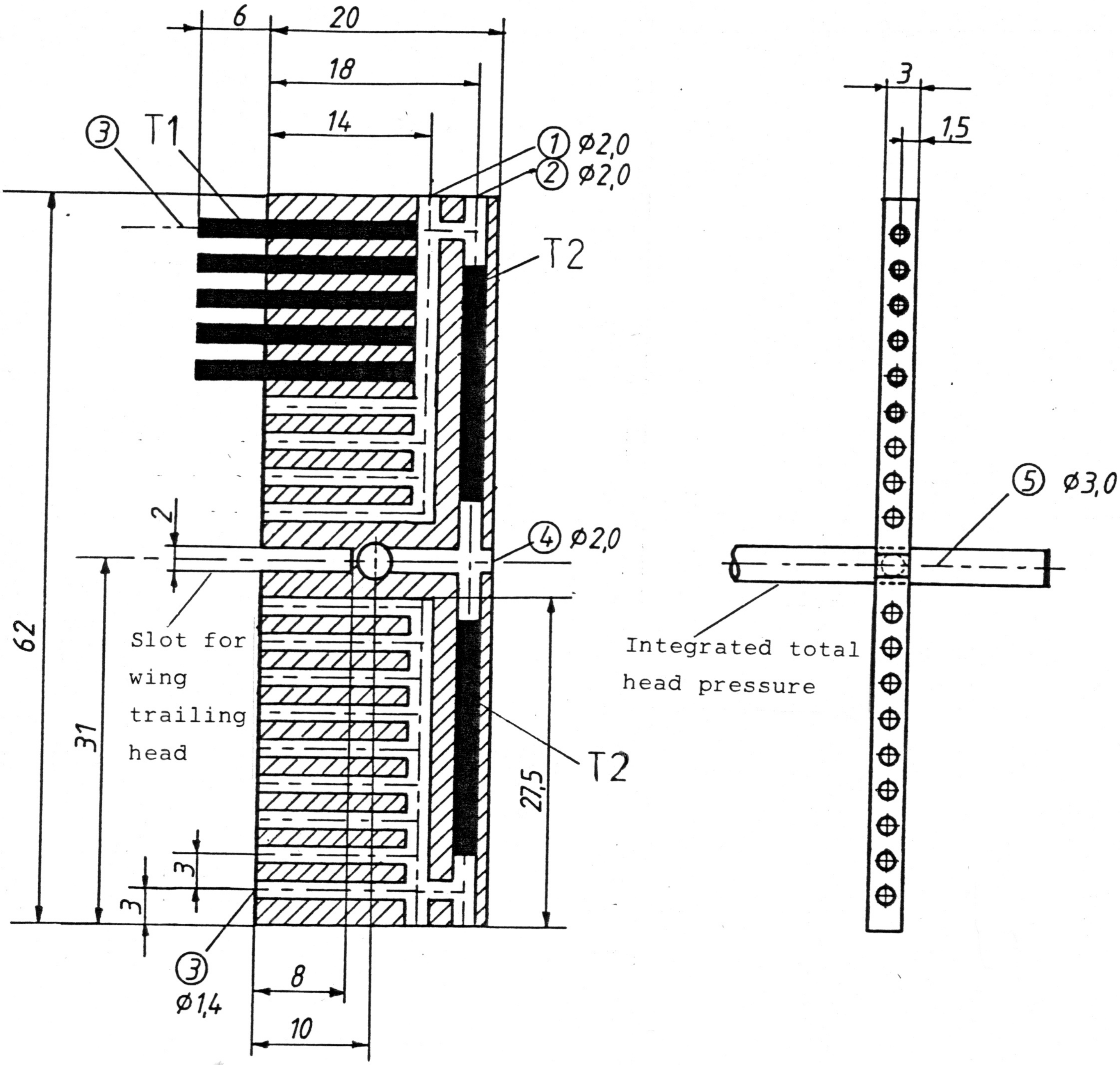


Fig. 8: Polar from rake due to fig.8 in comparison with polar from tunnel rake.



T1 o.d.= 1.4 mm length 19 mm
i.d.= 1.2 mm

T2 o.d.= 2.0 mm length 20 mm
i.d.= 1.0 mm

Dimensions in millimeters

Materials

body - aluminum
tubes - stainless steel

Fig. 7: Construction of an integrating rake for use at the wing trailing edge.

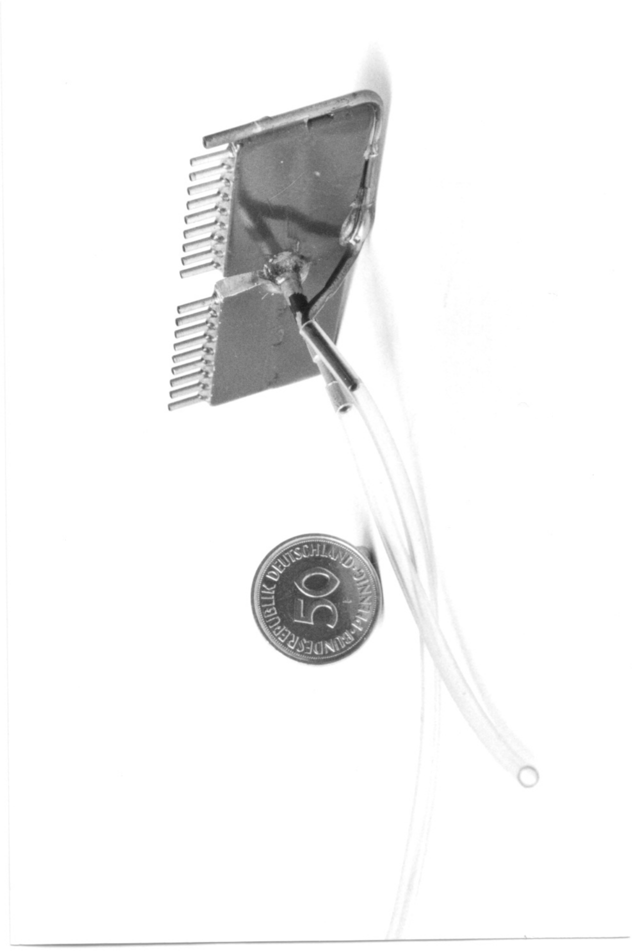
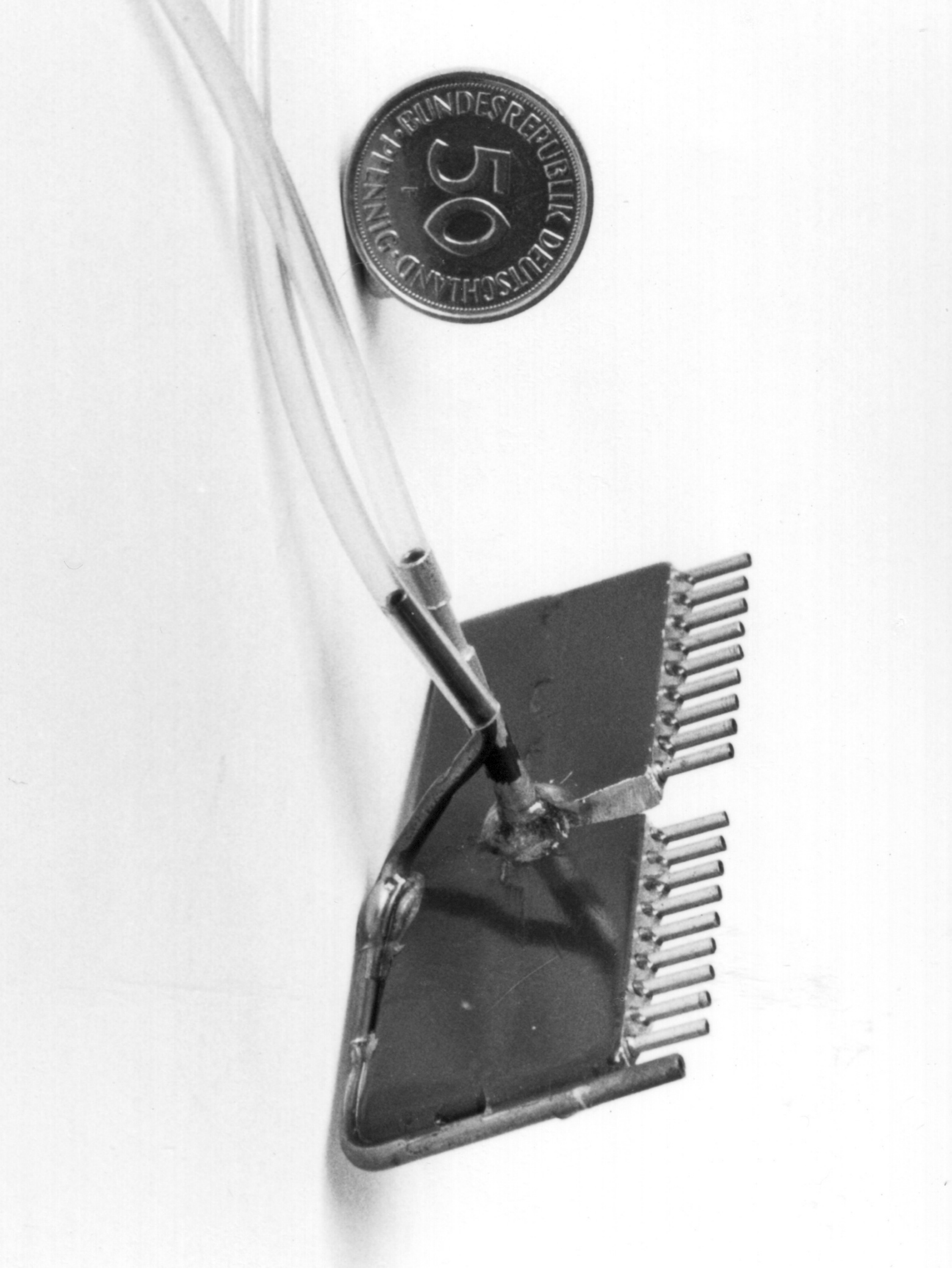


Fig. 9: Photograph of rake due to fig.8 with an additional tube for total head outside the boundary layer.



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