Drag Measurements on Airfoils

D.Althaus *

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The drag of airfoils is evaluated from the loss of total head in the wake. This is achieved either by an integrating rake positioned vertically to the trailing edge in some distance from the airfoil, or the wake is traversed by a single Pitot-tube point by point and the readings are integrated subsequently. In both cases the drag is evaluated only for a distinct plane in spanwise direction z. If the drag would be measured by a balance, the mean value over the whole wind tunnel model could be attained. But because of the undefinable influences of the tunnel walls this procedure cannot be used.

In the Laminar Wind Tunnel of the Institut for Aerodynamics of the University of Stuttgart drag is measured by an integrating rake, which includes static tubes and tubes for detecting the direction of flow.(Fig.1). The rake can be moved vertically to the trailing edge of the model and can be rotated in the direction of flow. It automatically positions in the middle of the wake and in flow direction. Originally the rake was fixed at some half of the span of the wind tunnel model in the middle of the test section. In recent time the traverse installation was completed to allow for movement of the rake in spanwise direction. Its position is controlled by an electric potentiometer. When measuring the drag coefficient in spanwise direction the rake is moved with a small constant velocity along the span. Pressure datas are sampled by an analog-digital converter with a frequency of about 20 Hz and stored by digital computer. Drag values are evaluated and plotted on an x-y-plotter on line. At the end

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* Institut für Aero- und Gasdynamik der Universität Stuttgart

of the traverse the datas for a length of 30 cm are integrated and plotted as a mean value line. Fig.2 shows an example for the measurement of drag coefficient c_D in spanwise direction z at a constant angle of attack $\alpha = 3^{\circ}$ and 4 Reynoldsnumbers on an airfoil. At small Reynoldsnumbers the drag shows considerable, nearly periodical variations along the span. At the example shown, the maximum deviations from the mean are about ± 15 per cent. With the Reynoldsnumber going up the amplitude becomes smaller. At about Re = 3 millions the drag coefficient is nearly constant along the span.

If the drag of an airfoil is only measured in a distinct plane considerable differences can arise. With this in mind it was understood why at retesting of wind tunnel models after a longer time different drag coefficients were measured: the rake was not installed at the same position z after a change in installation. Further more, this is an explanation, why in different wind tunnels or at flight tests different drag coefficients are measured for the same airfoil.

Periodical oscillations of drag in spanwise direction are found at nearly all airfoils. At first irregularities in the wind tunnel flow were thought to be encounted. However, not even by artificial disturbances simulated by 5 cm wide rods behind the last screen in the contraction part of the tunnel, any variations of drag could be generated. The fact, that the amplitudes become smaller with growing Reynoldsnumber, does not hold for this assumption.

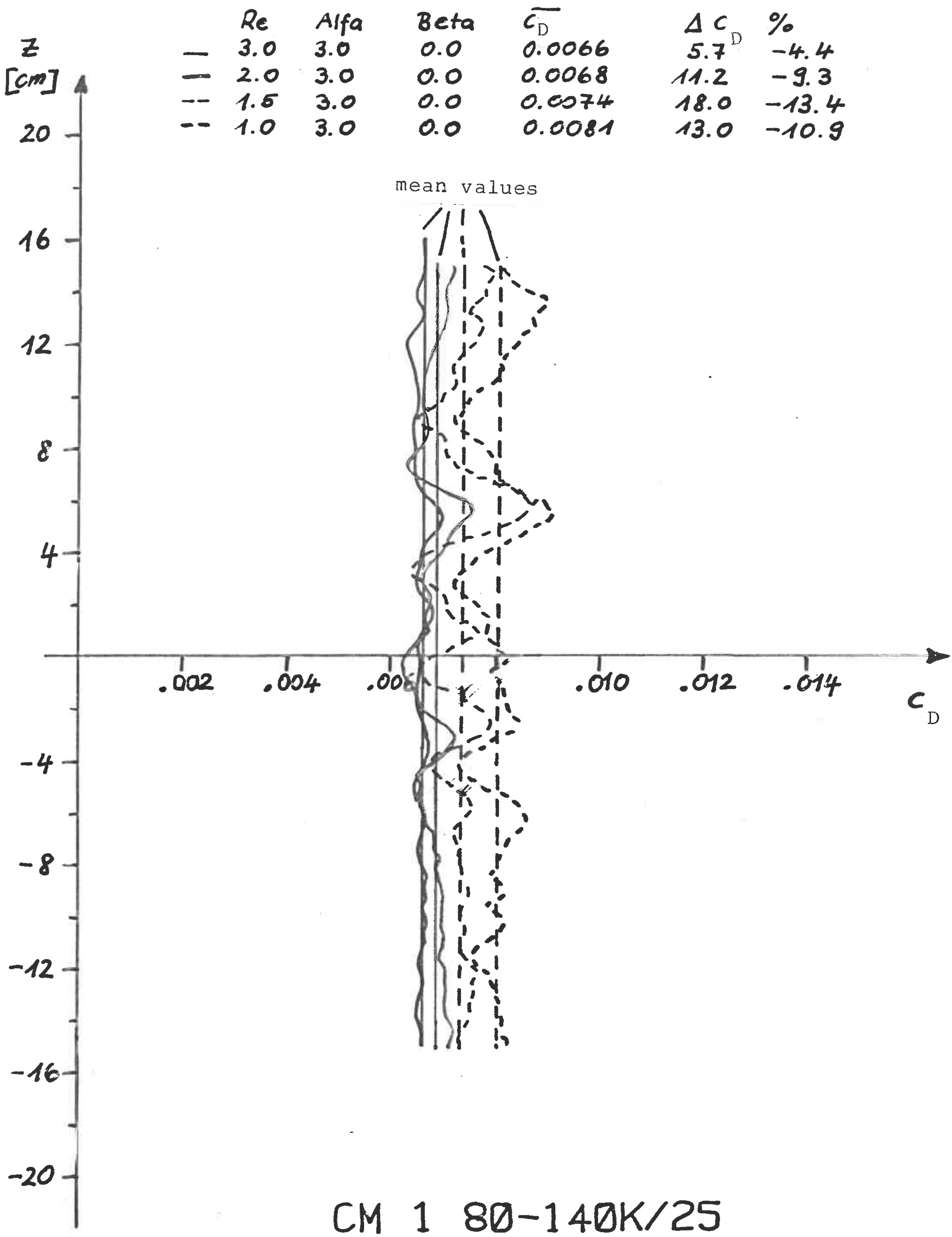
Fig.3 shows drag measurements in spanwise direction for another airfoil. In addition the behaviour of the drag portions of the upper and lower sides of the airfoil, measured by a rake gliding on the airfoil surface at the trailing edge, are shown. These portions of drag called c'_D are not in scale with the total drag coefficient c_D. The drag along the lower side is constant while on the upper side periodical variations of drag with a wave length of about 3 cm are observed. They show again in the variation of the total drag coefficient c_D. Further experiments and boundary layer measurements made on different wind tunnel models revealed that these oscillations are caused by counter-rotating longitudinal vortices in the turbulent boundary layer having their origin in the laminar separation bubbles. With growing Reynoldsnumber the laminar separation bubbles become smaller, boundary layers become thinner and the amplitudes of the drag oscillations deminish (see Fig.1). When the laminar separation bubble disappears, the vortices fade away too. The development of the amplitudes along their way depends on the curvature of the surface: by a concave curvature the amplitudes are amplified, by convex curvature they are damped. Owing to these longitudinal vortices all boundary layer parameters show oscillating character in z-direction. No boundary layer theory can take account of this effect until now. In addition laminar separation bubbles cannot be treated satisfactory by theory.

Experience shows that there is nearly no airfoil without longitudinal vortices. Such an airfoil should have no laminar separation bubbles or convex curvature of its surfaces. Before measuring a lift drag polar in the Laminar Wind Tunnel the drag is measured in spanwise direction as shown in Fig.1. The rake then is positioned at a point z having medium drag coefficient and stays there while measuring the rest of the polar. The z-position of the vortices merely varies with the angle of attack. The z-position of the rake during the measurement of the polar is noted on the diagrams.

Because of the appearance of longitudinal vortices in turbulent boundary layers and the associated drag oscillations in spanwise direction, comparison of various drag measurements is only comparable if drag measurements in spanwise direction are available as well.

Airfoil in the test section of the
Laminar Wind Tunnel with the rake
in the background

Fig. 1



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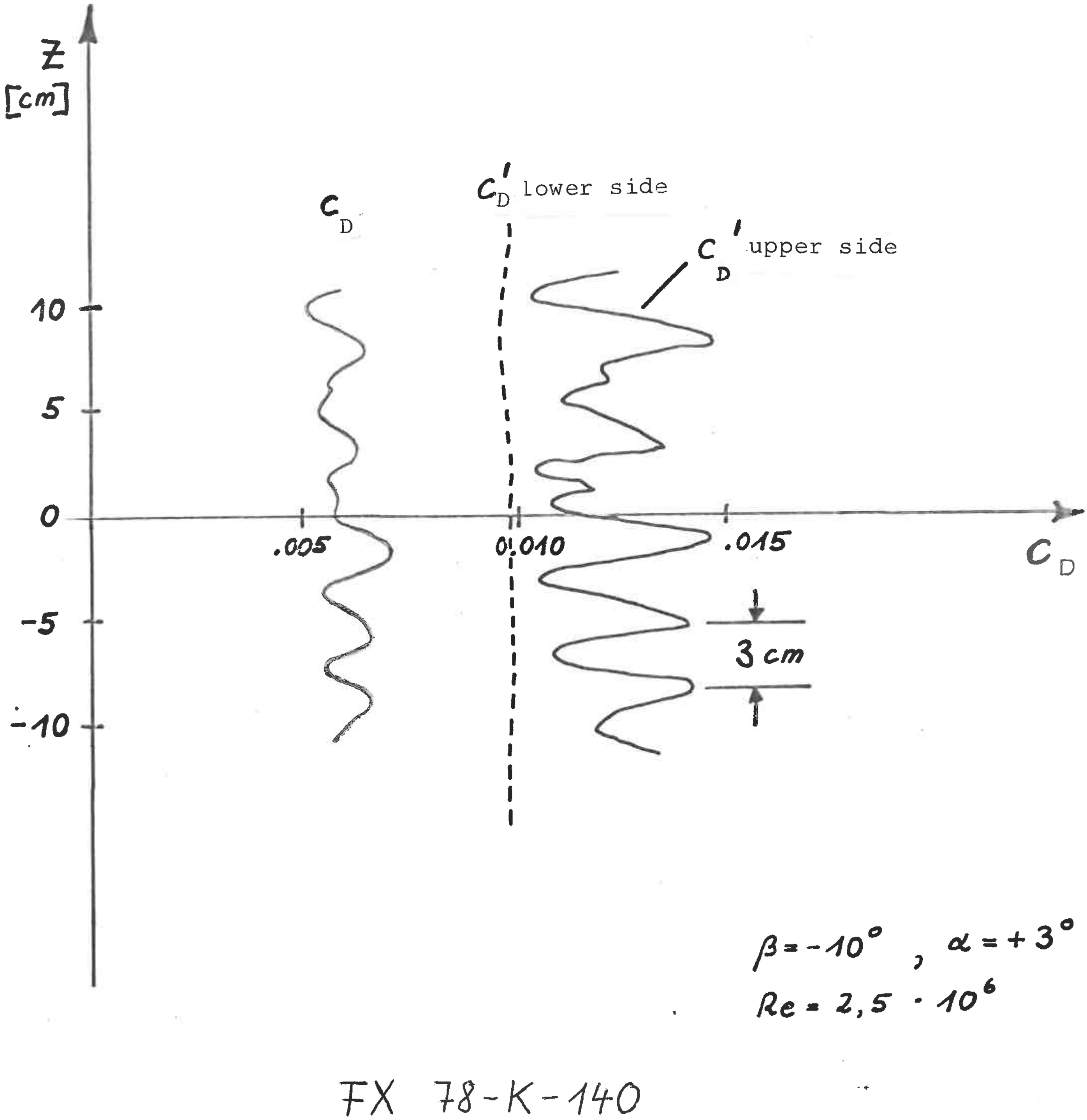
Drag coefficient in spanwise direction

Fig. 2



Drag coefficient in spanwise direction

Fig. 3