THE AERODYNAMIC DRAG; EXPERIMENTS ON LAKE GENEVA

Walter H. Graf and J.-Patrick Prost

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Contribution au Symposium International
AIRH, Cagliari, Italia, 10-14 septembre 1979

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Archiv für Meteorologie, Geophysik und Bioklimatologie,

Juin 1980
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ABSTRACT

The presently available data, obtained during a measuring campaign on the Lake Geneva, permitted a preliminary study on the aerodynamic drag coefficient, Cy. The LEMAN data are obtained for 3 different periods at a single station (buoy) on the lake. The presently available data are presented and compared with the literature. It is recommended to use for wind speeds $-5 \text{ m/s} < U_{10} < 15 \text{ m/s}$ - a Charnock relation with $a = 81$; for wind speeds $-U_{10} < 5 \text{ m/s}$ - a dispersive trend is evidenced which apparently depends on a stability criterion.

INTRODUCTION

The sea and the atmosphere are a coupled system; exchanges of momentum, heat and moisture take place at its interface. The fluxes are (Webb, 1965) (for symbols see end of paper):

- momentum flux: $T = -p \frac{\partial u'w'}{\partial y} = p \frac{\partial u}{\partial y}$
- moisture flux: $E = \frac{p q'w'}{K} = -p K \frac{\partial q}{\partial y}$
- heat flux: $H = \frac{p c_p \partial T'}{\partial T} = -p c_p K \frac{\partial T}{\partial y}$

It is often suggested that these fluxes are nearly constant "in the first tens of meters" (Pond, 1972). In above equations (1) to (3) the fluxes are expressed as turbulent fluxes as well as with the "bulk aerodynamic method" in terms of mean gradients. As a first approximation the transfer coefficients $K_M$, $K_E$ and $K_H$ are taken equal to unity and yet another convenient way to express these fluxes is (Neumann and Pierson, 1966, p. 413):

$$T = p c_p \frac{u_y^2}{y}$$
$$E = \frac{p c_p (q_y - q_y u_y)}{y}$$
$$H = \frac{(p c_p) c_p (T_y - T_y u_y)}{y}$$

These relations represent "for operational, parametric usage ... as good an estimate as can be justified on the basis of routine observations" (Kraus, 1972,
The purpose of this paper is to present preliminary information on the C\_y-value obtained from measurements over the water surface of the Leman.

THEORETICAL CONSIDERATIONS

Proposed is that the aerodynamic drag or frictional coefficient, C\_y', is determined from eq. 4 which with the frictional velocity \( u_* = \sqrt{\gamma/\rho} \) renders:

\[
C_y = \frac{\partial u_y}{\partial y} \tag{4'}
\]

The right side of eq. (4') is an indication of the velocity distribution in the boundary layer.

The diabatic wind profile shall be given as:

\[
y u_y = S_M \frac{Y}{L} \tag{7}
\]

with \( S_M \frac{Y}{L} \) as an unspecified stability function; \( L \) is the so-called Monin-Obukhov length expressed with:

\[
L = - \left( \frac{\rho u_*}{\rho' w'} \right) \frac{g \gamma}{\kappa g} \tag{8}
\]

The \( S_M \frac{Y}{L} \) term is frequently expressed with a power series or:

\[
S_M \frac{Y}{L} = 1 + \alpha \frac{Y}{L} \ldots \tag{9}
\]

There exists an extensive literature (Plate, 1971; Kraus, 1972) on the form and the \( \alpha \)-values in eq. (9), with average values of \( 4 < \alpha < 5 \). If eq. (9) is substituted into eq. (7) and integration is performed, a log-linear velocity profile is obtained, or:

\[
\frac{u_y}{u_*} = \frac{1}{k} \left[ \ln \frac{y}{y_o} + \alpha \frac{Y}{L} \right] + Cte \tag{10}
\]

Evaluation of the constant, Cte, is obtained by introducing the so-called roughness-length, \( y_o \), and eq. (10) reads thus:

\[
\frac{u_y}{u_*} = \frac{1}{k} \ln \frac{y}{y_o} + \alpha (y - y_o)/L \tag{11}
\]

For neutral conditions, with \( S_M \frac{Y}{L} = 1 \), "the lowest meter of the atmosphere is approximately neutral, except when the windspeed is low" (Tennekes et al., 1972, p. 100) - eqs. (7) and (11) read respectively:
The roughness length, $y_o$, for a flat plate with sand of diameter, $d$, was given (Schlichting, 1968) as $y_o = d/30$ and for vegetation of crop height, $h_c$, (Plate, 1971, p. 27) as $y_o = 0.15 h_c$. For wind over a water surface no conclusive information seems to be available. It appears, however, that the $y_o$ value must be dependent on the "sea-state" and that there exists a feedback mechanism between wind velocity, $u_y$, and the roughness length, $y_o$.

From the available literature one is lead to conclude that there exist 3 zones, classified according to the types of wind (velocities), namely: breezes, light winds and strong winds.

For strong winds the roughness values, $y_o$, and thus the drag coefficient are constant or

$$C_{10} = C_{te}$$

Kraus (1972) - postulating a constant relationship for $u_y/u = 0.05$ - derives theoretically this constancy and states "that the wind interacts primarily with the high frequency part of the waves spectrum, which is quickly saturated and has the same power over a wide range of wind velocities; ... above a level which is a small function of most wavelength, the wind apparently does not know what the waves are like". However, there exists disagreement as to what this value of constancy is and for what wind-velocity range it is applicable. Kraus (1972) proposed a theoretical value of $C_y = 2 \times 10^{-3}$; reviewing experimental data, this value is given as $C_{10} = 1.3 \times 10^{-3}$. Wu (1969) proposed: $C_{10} = 2.6 \times 10^{-3}$ if $u_{10} > 15$ m/s, while Sethuraman et al. (1975) find constant values, which depend on the roughness categories and all for $u_6 > 3.5$ m/s. Furthermore Kraus (1972, p. 161) indicated that the $y_o$-values are almost independent upon the stratification (Ri-Number) for $u_{10} \geq 11$ m/s since for the strong winds convection is always forced.

For light (medium) winds there seems to be agreement that the drag coefficient varies "weakly" with wind velocity or

$$C_{10} = f(u^n)$$

Again considerable disagreement is evidenced in the literature as to wind range of application of this dependency and the numerical form of above relation. Much of the data have been compared with the "Charnock" dimensionless roughness scale of:

$$y_o = \frac{u^*}{g \alpha}$$
where $a$ is a constant. Stewart (1974) seems to imply that this constant lies between $28.5 < a < 81$ for a data range of $3 < u_{10} < 13$ m/s. However, Stewart (1974) also demonstrates that the same data have a constant $C_{10}$ value "in the neighbourhood of $1.3 \times 10^{-3}$ plus or minus some 20%". It should be mentioned that Wu's (1969) conclusion is in agreement with $a = 64$. Since the variation of $C_{10}$ values with $u_{10}$ is not conclusive, Pond (1972) in a review article suggested:

$C_{10} = 1.5 \times 10^{-3} \pm (10\text{-}20\%)$, apparently valid for a windrange from 2 to 16 m/s.

For breezes (weak winds) there exists neither much nor conclusive literature. It is probably theoretically sound to expect that weak winds act aerodynamically "smooth" and a Reynolds number relationship such as

$$C_{10} = \frac{Y u_{10}}{V}$$

is important. With meager experimental evidence Wu (1969) proposed a relationship for eq. (15). Of importance is the experimental work of Mitsuta and Boullery (1977); for a velocity range of $0.1 < u_2 < 4$ m/s, the drag coefficient was $4 \times 10^{-4} < C_2 < 10^{-1}$. The enormous dispersion could be explained with the fact that density stratification plays a most important role at low wind velocities; this is evidenced by Kraus (1972, p. 161). Furthermore, there is a tendency for $y_0$ values to be larger in stable than in unstable stratification; neutral stratification data falling somewhere in between.

In addition to the wind velocity and the density stratification, other parameters have more recently been studied which possibly could explain the scatter in the $C_2$ values. Donelan (1977) investigated the “sea state” as it affects the drag coefficient. The importance of the fetch is shown by Donelan (1974) and Stewart (1974). Boullery (1977) found the drag coefficient to vary with the gustiness of the wind. However, none of above “new” parameters bring sufficient order into the data.

Finally one cannot help but agree with the strong warning by and to many researchers, and so well said by Stewart (1974): "There is always a substantial amount of scatter in published drag coefficient results. Much of this is undoubtedly due to the technical difficulties of making measurements themselves".

DESCRIPTION OF EXPERIMENTS

The measurements

A detailed description of our experimental programme has been given by Graf et al. (1979) and Prost et al. (1977). The instruments used were: (i) 3 wind speed sensors (Aanderaa WSS 2219), (ii) a wind direction sensor (Aanderaa WDS 2053),
(iii) a magnetic compass and (iv) 2 temperature sensors (Aanderaa TS 1289). All the "air" instruments were mounted on the mast of the anemometric station (see Fig. 6 in Graf et al., 1979) and as such were subject to the flow and wave induced movement of this station. No effort was made to "clean" the data of this effect.

The data utilised were obtained at the site "V" described by Graf et al. (1979, Figs. 2 and 14) where the measuring campaign lasted from 9.12.1977 to 15.2.1978. All aerodynamic parameters were, for various reasons (see Graf et al., 1979, Table 4.4), recorded for only a limited duration of 23.1.1978 to 15.2.1978. The parameters - measured every 10 minutes - were: the wind velocity (average velocities during 10 minute intervals at 6.1 m, 2.2 m and 0.8 m) and its direction (instantaneous at 5.0 m) and the temperature (its instantaneous values in air at 5.0 m and at the water surface, ca. - 1.0 m).

Within the above duration of registration, 3 periods of 24 hours have been selected for analysis. This selection aimed at obtaining a maximum spread in intensity of winds. Furthermore, for this site only fetches for SW winds can reasonably be calculated. The 3 periods are:

Period 1 (29.1.78 at 13.00 to 30.1.78 at 13.00): with medium winds of $5 \leq u_{10} < 12$ m/s and some weak winds of $u_{10} < 5$ m/s, coming from SW; the preceding aerodynamic situation was similar.

Period 2 (2.2.78 at 0.20 to 3.2.78 at 0.20): beginning with a strong wind (gust) from SW (with values up to 15 m/s) after a relatively calm preceding aerodynamic situation. All winds are $> 7.5$ m/s.

Period 3 (31.1.78 at 0.00 to 1.2.78 at 0.00): with weak winds of $2 \leq u_{10} < 6$ m/s coming more or less from NWW and SEE.

The data

The 3 periods resulted in $144 \times 3 = 432$ recordings. However, given the precision of the anemometers and their positioning on the mast, one sometimes obtains:

1. at all levels the same velocities or
2. at higher levels lower velocities than at lower levels. Even if the data reflect a "real" phenomenon, they had to be eliminated, since the analysis bases itself upon the "logarithmic distribution". In this way the recordings reduce themselves for period 1: 142 profiles, for period 2: 139 and for period 3: 90.

With the wind velocities measured at the three levels a regression analysis based on a logarithmic distribution allows the determination of $u_{10}$, $u_5$, $u_3$ and $u_c$; subsequently the "experimental" velocities are corrected for a wind induced surface current, $u_s = 0.55 u_c$. 


Fig. 1. Drag coefficient, \( C_{10} \), and roughness length, \( y_0 \), as a function of wind speed, \( u_{10} \); the LEMAN data (legend see Fig. 2) and in insert data of the literature.
Finally we should like to stress that our recordings - the LEMAN data - were used as such and were not "corrected" for supplementary effects caused possibly by the recording instruments and/or the floating anemometric station.

PRESENTATION OF DATA

Drag coefficient and roughness length

A most useful - and indeed often employed - display of the data is obtained by plotting \( C_{10} \) and/or \( y_o \) versus \( u_{10}' \). In the insert of Fig. 1 this is done for relationships as discussed in the previous section; all of these data are obtained for neutral conditions. For the sake of comparison, the smooth flat plate is also indicated; to be noted is that the latter presents a lower limit to above relations. Since relationships for low wind speeds are scarce, we indicated also two sets of data for low wind speeds; these data are for neutral and non-neutral conditions. On Fig. 1 and Fig. 2 the data of our field experiments, the LEMAN data, are represented.

Fig. 2. Roughness length, \( y_o \), as a function of wind speed, \( u_{10}' \); the LEMAN data compared with Brocks' data.
plotted is the wind speed, \( u_{10} \), against the drag coefficient, \( C_{10} \), and the roughness length, \( y_0 \), respectively. Comparing now the LEMAN data with the literature, as displayed in the insert of Fig. 1, one notices: (i) for wind speeds, \( 5 \text{ m/s} < u_{10} < 15 \text{ m/s} \), the LEMAN data (neutral and non neutral) fall slightly underneath the Charnock relation with \( a = 81 \); realizing the fact that the LEMAN data are collected with certain experimental difficulties, we are led to conclude that a Charnock relation with \( a = 81 \) might be sufficiently appropriate; (ii) for wind speeds, \( u_{10} < 5 \text{ m/sec} \), the LEMAN data exhibit the dispersive trend similar to the one of Boullery (1977) and Brocks et al. (1970); no specific conclusion can be drawn.

If the LEMAN data are compared with the values supplied by Brocks et al. (1970), above remarks are further evidenced; this is done with Fig. 2. Our conclusion corroborates with Kraus (1972, p. 160): "The influence of the density stratification ... is larger at low wind speeds ... The resulting decrease in the spread of \( y_0 \) with increasing wind velocity is illustrated ..." The Brocks' data seem to show that for unstable stratification the \( y_0 \)-values are in general lower than the stable ones. The LEMAN data do not show this pronounced tendency which is also indicated in Fig. 3.

Atmospheric stability

Stability of the atmosphere is described with either the stability function, \( S_{M} \), or the gradient Richardson-Number, \( R_i \) - see eq. (8). In the present study we used a bulk Richardson Number, \( R_b \), indicating the difference between the air...
layer temperature at 5 m, T_5, and the water surface temperature, T_s, or:

\[ \frac{T_5 - T_s}{u_5} = \text{const.} \]  \(\text{RI}(5 - 0)\) (16)

where \(u_5\) is the wind velocity at 5 m. A similar stability relation was used by Donelan et al. (1974) and Boullery (1977). Either of the above criteria becomes zero for neutral conditions; it is numerically positive for stable and negative for unstable conditions.

In Fig. 3, the LEMAN data are plotted with above stability criteria versus the drag coefficient, \(C_5\). First one notices that during the present measuring campaign which falls into the winter months, the majority of data are for unstable values. For small \(\text{RI}(5-0)\)-values (-0.1 < \(\text{RI}(5-0)\) < 0.02) the data present themselves with a reasonable spread. An average \(C_5\)-values of \(C_5 = 1.30 \times 10^{-3}\) (corresponding: \(C_{10} = 1.15 \times 10^{-3}\)) can be taken; this values being slightly higher for positive \(\text{RI}(5-0)\) (stable) and slightly lower for negative \(\text{RI}(5-0)\) values (unstable). For \(\text{RI}(5-0)\) values smaller than -0.1 the spread of the data is considerable and thus no conclusion can be drawn from them.

ACKNOWLEDGEMENT

This work is partially sponsored by the Swiss National Scientific Foundation (SNF/SNSF) under its special program "Fundamental problems of the water cycle in Switzerland".

SYMBOLS

- \(\rho\) air density
- \(V(u,v,w)\) velocity vector
- \(q\) specific humidity
- \(\Theta\) potential temperature
- \(c_p\) specific heat at constant pressure
- \(\bar{\cdot}\) indicating turbulent fluctuations
- \(\bar{\cdot}\) mean value
- \(y\) height of observation
- \(s\) (subscript) water surface
- \(a\) air
- \(C_y\) drag coefficient, with respect to the observation height \(y\) (i.e.: \(C_{10}, C_s\))
- \(u_*\) friction velocity
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<th>Symbol</th>
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<tr>
<td>k</td>
<td>Karman's constant</td>
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<tr>
<td>$S_n(y/L)$</td>
<td>stability function</td>
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<tr>
<td>T</td>
<td>absolute temperature</td>
</tr>
<tr>
<td>Ri</td>
<td>gradient Richardson Number</td>
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<tr>
<td>$R_b$</td>
<td>Bulk Richardson Number</td>
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<tr>
<td>g</td>
<td>gravitational acceleration</td>
</tr>
<tr>
<td>$y_o$</td>
<td>roughness length</td>
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<tr>
<td>a</td>
<td>Charnock's constant</td>
</tr>
<tr>
<td>v</td>
<td>kinematic viscosity</td>
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**REFERENCES**


SYNOPSIS
Experiments on Lake Geneva render preliminary informations on the
erodynamic drag of a lake surface. The data are presented in form
of Fig. 1 according to eq. (3); an attempt is made to classify them
in a dimensionless way according to eq. (4) in Fig. 2.
Une campagne de mesures sur le Léman a permis d'obtenir quelques in-
fomations préliminaires sur le "coefficient de frottement aerodyna-
mique" de la surface d'un lac. Les données sont représentées à la
Fig. 1 suivant la relation (3); une tentative de classification adi-
mensionnelle de ces données suivant la relation (4) est proposée à
la Fig. 2.

COEFFICIENT DE FROTTEMENT FONCTION DE LA VITESSE DU VENT
Des mesures des paramètres météorologiques moyens usuels obtenus à
partir d'une station flottante sur le Léman (voir GRAF et al., 1979)
pendant l'hiver 1978, ont permis d'obtenir des résultats intéressants
concernant le transfert de quantité de mouvement à l'interface air-
eau. Généralement le flux turbulent, \( I \), est obtenu à partir du vent, \( U_y \),
au niveau \( y \), en introduisant un coefficient appelé "coefficient de
frottement", défini par:
\[
C_{10} = \frac{\tau}{\rho U_{10}^2} \quad \text{ou} \quad C_{10} = (u_*/U_{10})^2
\]
avec \( u_* = \sqrt{\frac{\tau}{\rho}} \), vitesse de frottement et \( U_{10} \), vitesse moyenne sur 10 mi-
utes du vent à 10 m au-dessus du niveau moyen du lac. Cette vitesse
a été calculée à partir des 3 vitesses moyennes mesurées aux niveaux
0.8 m, 2.2 m et 6.1 m en admettant une distribution de vitesses logarith-
mique valable pour des conditions de stabilité atmosphérique proche
de la neutralité:
\[
\frac{U_y}{u_*} = k \frac{1}{y_0} \cdot \ln \left( \frac{y}{y_0} \right)
\]
avec \( y_0 \), longueur de rugosité et \( k \), constante de Karman (0.4).
Nous disposons de 281 données valables correspondant à 2 périodes de mesures différentes d'une journée chacune. Elles sont représentées à la Fig. 1 sous la forme classique:

\[ C_{10} = f(U_{10}) \]  

(3)

Sur cette figure, la droite en trait plein représente la régression linéaire d'équation:

\[ C_{10} = (0.05U_{10} + 0.56) \times 10^{-3} \]

obtenue par la méthode des moindres carrés avec toutes les données correspondant à \( U_{10} > 5 \text{ m/s} \) (le calcul ne porte alors que sur 270 données). Le coefficient de détermination de 0.36 dénote cependant une forte dispersion des données autour de cette droite.

On note également qu'avec le paramètre de stabilité choisi:

\[ R_b = \frac{(T_5 - T_s)}{U_5^2} \]

avec \( T_5 \) et \( T_s \), températures de l'air à 5 m et de l'eau en surface, les données sont toutes ou presque proches de la neutralité, à l'exemple des données correspondant aux vents faibles, \( U_{10} < 5 \text{ m/s} \), pour lesquels l'équation (2) n'est alors plus valable.

En comparant ces valeurs du "coefficient de frottement" avec celles obtenues sur l'océan ou les lacs avec la même méthode des profils (voir GARRATT, 1977, Tab. 2 et Fig. 3), on constate une croissance identique de \( C_{10} \) avec \( U_{10} \), avec cependant des valeurs de \( C_{10} \) dans notre cas légèrement inférieures, \( C_{10} = 1.0 \times 10^{-3} \).
Fig. 2 Coefficient de frottement, $C_{10}$, fonction du nombre de Reynolds de fetch, $(U_{10}F)$; le paramètre est la "rugosité relative".
REPRESENTATION ADIMENSIONNELLE DU "COEFFICIENT DE FROTTEMENT"

Par analogie à l'écoulement sur une plaque, il est tentant de représenter le "coefficient de frottement" à la surface d'un plan d'eau en fonction d'un paramètre adimensionnel tel que le nombre de Reynolds, dans lequel le terme de longueur choisi est le fetch, $F$, associé directement aux ondes qui créent la rugosité de surface. Nous proposons donc pour les plans d'eau confinés (c'est-à-dire pour des fetchs limités), la relation suivante:

$$C_{10} = f\left(U_{10}, F/v, H_{1/3}/y_0\right)$$

avec $F$, fetch efficace et $H_{1/3}$, hauteur de la vague significative.

Dans notre cas le fetch efficace a été calculé uniquement pour des vents $U_{10} \geq 5 m/s$ compris dans le cadran S-O, en suivant la méthode proposée par le U-S Army Coastal Engineering Research Center (1975, pag.: 3-29 à 3-33); puis la hauteur de la vague significative correspondante a été calculée au moyen de la formule :

$$\frac{g \cdot H_{1/3}}{U_{10}^2} = 0.0305 \cdot \left(\frac{g \cdot F}{U_{10}^2}\right)^{0.466}$$

proposée par WU (1969, pag.: 450) à partir de données océaniques.

Avec nos données le fetch efficace oscille entre les valeurs 8,4km et 17,2km et les hauteurs de vague significative entre 0,50m et 1,5m.

Nos données sont représentées à la Fig. 2 selon la relation (4). On constate tout d'abord qu'elles tombent largement au dessus de la courbe lisse. Contrairement au cas de la plaque immobile le "coefficient de frottement" semble dépendre du nombre de Reynolds du fetch lié aux ondes de surface. Cette dépendance est mise en évidence sur la figure à l'aide du paramètre adimensionnel, $H_{1/3}/y_0$, qui représente directement la rugosité du plan d'eau fonction du développement du champ de vagues le long du fetch. Ainsi à une augmentation du "coefficient de frottement", $C_{10}$, correspond une diminution du paramètre de rugosité relative, $H_{1/3}/y_0$. Cependant la variation du fetch efficace est trop faible et par là la gamme des hauteurs de vagues significatives trop faible, pour que l'on puisse conclure de façon plus précise avec les seules données dont nous disposons.

BIBLIOGRAPHIE


Aerodynamic Drag and Its Relation to the Sea State:  
With Data From Lake Geneva

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With 11 Figures  
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Summary

In a recent review on the drag coefficient, Garrat ([5], p. 915) pointed to the fact that "The effect (if any) of the fetch, wind duration and unsteadiness remains obscure in this experimental data scatter". The present paper makes an attempt to analyse, in the light of a fetch dependency, data which have been accumulated on the Lake of Geneva. Postulated is a possible functional relationship between the local drag coefficient, $C_{10}$, and a fetch Reynolds number, $(U_{10}F)/v$, with a dimensionless roughness, $F/\eta_0$, as parameter. Subsequently, a possible relationship between the roughness parameter and the sea state (expressed presently with the significant wave) is discussed. The present study should be considered as preliminary in as much as it served to establish another field programme on Lake Geneva.

Zusammenfassung

Aerodynamische Reibung und deren Beziehung zum Seegang; Experimente vom Genfersee

In einem Artikel von Garrat ([5], S. 915), der sich zusammenfassend und kritisch mit der jüngsten Forschung über die aerodynamische Reibung über einer Wasseroberfläche aus- einandersetzte, heißt es: „Die Auswirkungen des Fetches, der Dauer und der Unstetigkeit eines Windes sind unbekannt und verstecken sich wohl hinter der Streuung der experimentellen Resultate“. In unserem Artikel ist ein Versuch unternommen worden, vorhandene Resultate von Experimenten am Genfersee auf eine Fetchabhängigkeit zu untersuchen. Dabei wird eine funktionelle Beziehung zwischen dem lokalen Reibungs- oder Widerstandskoeffizienten, $C_{10}$, und einer Fetch-Reynoldszahl, $(U_{10}F)/v$, mit einer dimensionlosen Rauhigkeit, $F/\eta_0$, als Parameter vorgeschlagen. Weiter wird gezeigt, daß eine Beziehung zwischen dem Rauhigkeitsparameter und dem Seegang (ausgedrückt als signifikante Welle, $H_{1/3}$) möglich ist.

Diese Studie sollte als Vorstudie angesehen werden; sie diente unter anderem als Grundlage für ein größeres aerodynamisches Projekt am Genfersee.
La trainée aérodynamique en relation avec l'état de surface du lac (Le Léman)

Dans un article récent sur le coefficient de frottement, Garrat ([5], p. 915) laisse supposer que « les effets du fetch, de la durée et de la variabilité du vent s'ils existent, demeurent obscurs dans la dispersion des données expérimentales ». Dans cet article, on essayera d'analyser l'éventuelle dépendance du fetch sur les données obtenues au cours des campagnes de mesures sur le Léman. On admettra qu'une relation entre le coefficient de frottement local, $C_{10}$, et le nombre de Reynolds de fetch, $(U_{10}F)/\nu$, existe, avec la rugosité adimensionnelle, $F/\gamma_0$, comme paramètre. Puis on discutera de l'éventuelle relation entre le paramètre de rugosité et l'état de surface du lac (exprimé ici en fonction de la vague significative).

Cette étude est à considérer plutôt comme un travail préliminaire à l'établissement d'un nouveau programme expérimental projeté sur le Léman.

1. Introduction

The aerodynamic drag or frictional coefficient, $C_y$, is defined as:

$$C_y = \frac{T}{\rho U^2_y}$$

which with $\sqrt{\tau/\rho} = U_*$ renders:

$$C_y = (U_*/U_y)^2.$$  (2)

The right side of above equation is an indication of the velocity distribution in the air boundary layer.

In general, a diabatic wind profile is given as:

$$\frac{U_y}{U_*} = \frac{1}{k} \left[ \ln \left( \frac{y}{\gamma_0} \right) + \alpha(y/L) \right] + Cte$$  (3)

Evaluation of the constant, $Cte$, is obtained by introducing the roughness length, $\gamma_0$, and above equation reads:

$$\frac{U_y}{U_*} = \frac{1}{k} \left[ \ln \left( \frac{y}{\gamma_0} \right) + \alpha(y-\gamma_0)/L \right].$$  (4)

The argument, $\alpha(y/L)$, may be expressed as:

$$S_M(y/L) = 1 + \alpha(y/L)$$  (5)

where $S_M(y/L)$ is an unspecified stability function, with $L$ as the so-called Monin-Obukhov length. The $S_M(y/L)$ function is in turn related to the gradient Richardson Number, $Ri$, or

$$Ri = \frac{g}{\theta} \left( \frac{du}{dy} \right)^{-2} = \frac{fct(y/L)}{L}.$$  (6)
Aerodynamic Drag and Its Relation to the Sea State

In the present study we shall use a bulk Richardson Number, \( R_b \), indicating the temperature difference between the air layer at 5 m, \( T_s \), and the water surface, \( T_s \), or:

\[
R_b = \frac{(T_s - T_s)}{U_s^2}
\]

(7)

where \( U_s \) is the wind velocity at 5 m. A similar relation for the atmospheric stability has been used by Donelan et al. [3] and by Boullery [1].

For neutral and near neutral conditions, eq. (4) becomes:

\[
\frac{U_f}{U_s} = \frac{1}{k} \ln \left( \frac{y}{y_0} \right)
\]

(8)

The existing literature has recently been well reviewed by Garrat [5]; here it should suffice to make only a few statements particularly pertinent to our data. For light (medium) wind within a windrange of \( 2 < U_10 < 16 \) m/s, there seems to be agreement that the drag coefficient varies weakly with the wind velocity. Much of the data have been compared with the Charnock's non-dimensional relation:

\[
a = \frac{U_10^2}{g y_0}
\]

(9)

where \( a \) is a constant. In a critical review Stewart [15] implies that this constant lies between \( 28.5 < a < 81 \) for a range of \( 3 < U_10 < 13 \) m/s. It should be mentioned here that Wu's [19] conclusion is in agreement with \( a = 64 \). The above indicated numerical values are shown in Fig. 3. Also indicated is, for the sake of comparison, the smooth flat plate.

2. The Experimental Programme

The measurements: A detailed description of our experimental programme has been given by Graf et al. [6]. The instruments used were: (i) 3 wind speed sensors (Aanderaa WSS 2219), (ii) a wind direction sensor (Aanderaa WDS 2053), (iii) a magnetic compass and (iv) 2 temperature sensors (Aanderaa TS 1289). All the "air" instruments were mounted on the mast of the anemometric station and as such participated in the flow and wave induced movement of this station. No effort was made to clean the data of this effect.

The data utilised were obtained at the site "V" on Lake Geneva (see Fig. 1) where the measuring campaign lasted from 9. 12. 1977 to 15. 2. 1978. All aerodynamic parameters were, for various reasons, recorded for only the limited period of 23. 1. 1978 to 15. 2. 1978. The parameters — measured every 10 minutes — were: the wind velocity (average velocities during
10 minutes intervals at 6.1 m, 2.2 m and 0.8 m) and its direction (instantaneous at 5.0 m) and the temperature (its instantaneous values in air at 5.0 m and at the water surface, ca. —1.0 m).

Within the above duration of registration, 2 periods have been selected for analysis. The selection aimed at (i) obtaining a spread in wind intensity and at (ii) allowing the determination of the sea state for SW winds for this particular site, "V", with reasonable precision. The wind-roses given in Fig. 2 show:

For period 1 (from 29. 1. 1978, 13h00 to 30. 1. 1978, 00h00): 76.4% of the winds, measured at 6.1 m height fall between 5 to 10 m/s; of these winds, 75% come from directions between 165° < θ < 225°.

For period 2 (from 2. 2. 1978, 00h20 to 3. 2. 1978, 00h20): 84.5% of the winds, measured at 6.1 m height fall between 9 to 13 m/s; of these winds, 75% come from directions between 195° < θ < 265°.

The data: The 2 periods resulted in 144 × 2 = 288 recordings. However, not all of these data are deemed significative for further use. Two procedures of elimination were adopted:

a) In a previous investigation with the same data set (see Graf et al. [6]) it was shown that, for low wind velocities ($U_{10} < 5$ m/s), one may note a large scatter of the $C_y$ values, indicating the strong influence of the atmospheric stability. It is for this reason that in the present study only wind velocities $U_{10} > 5$ m/s are considered.

b) Considering the wind-roses (Fig. 2) and the topography of the lake and its surrounding, the sea state can be reasonably calculated for south-westerly
wind direction. In this study the calculations are performed for $195^\circ < \theta < 265^\circ$.

In this way the number of recordings available for further consideration is 83 for period 1 and 101 for period 2. In Table 1 all 288 recordings are listed; each line shows one recording and if above conditions are satisfied, its calculated values. In column 1 is indicated the date: month-day-hours-minutes. In columns 2 to 4 are given values of 10 minutes average wind velocities [m/s] measured at 0.8 m, 2.2 m and 6.1 m height respectively; in column 5 the instantaneous wind direction in degrees is shown. In column 6 are given the calculated wind velocities, $U_{10}$ [m/s], at 10 meters height, which were extra-
Table 1a. Lemon data - Period 1

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Note: The table continues with similar data for several more dates. The data includes wind speed (wind (m/s)), wave height, wave period, wave length, and wave peak and trough values for the specified dates.
### Aerodynamic Drag and Its Relation to the Sea State

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### Wind and Hydrometeor Data

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### Reynolds Number and Richardson Number

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R. H. Graf and J. P. Prost

polated using a regression analysis for a logarithmic velocity distribution (subsequently the “experimental” velocities are corrected for a wind induced surface current, \( U_s = 0.55 U_w \)). If \( U_{10} < 5 \text{ m/s} \) no more calculations are performed. In column 7 the drag coefficient, \( C_{10} \), is shown. In columns 8 and 9 the wind shear velocity, \( U_* [\text{cm/s}] \), and the roughness length, \( y_o [\text{cm}] \), obtained from the slope and the zero intersection of the regression line through the experimental data, are listed. From these values, the roughness Reynolds number, \( Re = U_* y_o / \mu \), is calculated and given in column 10. Measured air and water temperature [°C] are indicated in column 11 and 12, which allows calculation of a bulk Richardson number — see eq. (7) — given in column 13. If the two conditions mentioned above are not fulfilled, nor more calculations are performed. Otherwise the calculation of the effective fetch corresponding to the subsequent direction was performed, following a method outlined by the U. S. Army Coastal Engineering Research Center ([17], pp. 3–29 to 3–33). With this calculated value of the effective fetch [km] — given in column 14 — wave parameters can be obtained using the empirical formulae given by Wu ([19], p. 450) which correspond to oceanic data given, by Wiegel [18]. These parameters — the significant wave height, \( H_{1/3} [\text{m}] \), and the wave speed, \( C [\text{m/s}] \), as well as the minimum duration of wind to develop the significant wave, \( t_{min} [\text{h}] \) — are indicated in columns 15 to 17. These 184 data form the set of the “Leman” data which will be discussed in the next section.

3. Presentation of Data

3.1 \( C_{10} \) vs. \( U_{10} \), drag coefficient as a function of windspeed

The classic way of displaying the data

\[
C_{10} = f(U_{10})
\]  

is given in Fig. 3.

Despite the fact that it is not rigorously correct, we shall consider the present (winter) data as (near) neutral, having only in exceptional cases: \( R_b \ll -0.10 \), but in most cases: \(-0.10 < R_b < +0.05 \). In other words, the temperature difference between the water surface at \(-1.0 \text{ m} \) and the air layer at \(+5.0 \text{ m} \) was never larger than \( \Delta T = T_s - T_a = 3 ^\circ \text{C} \), on the average \( \Delta T = 1.5 ^\circ \text{C} \). Kondo ([10], p. 104) has shown graphically the effect of the temperature difference, \( \Delta T \), upon the drag coefficient; indeed in our wind velocity range this effect is usually small.

Comparing the present data with relationships proposed in the literature, it is to be noted that they fall consistently above a Charnock roughness scale of \( a = 81 \). While it is not impossible that our data contain, due to experimental difficulties, some systematic error, we shall continue to look...
for other possible systematic effects. This seems particularly justified, since most if not all, of above relationships were established to explain the data with “full or open fetch”, while in the present investigation on a lake only data with limited fetch are available. Low drag coefficients are also reported in the literature by Kraus [11] and Stewart [15]; they are reproduced in Fig. 5. A linear least square curve fit through the Leman data gives:

\[ C_{10} = (0.054 U_{10} + 0.52) \cdot 10^{-3} \]  

(11a)

or  

\[ C_{10} = \frac{k^2}{(\ln \frac{10^3}{y_0})^2} = 0.16 (6.91 - \ln y_0)^{-2} \]  

(11b)
where $U_{10}$ is in m/s and $y_0$ in cm. For the sake of comparison above relation is indicated in Figs. 3 and 5.

3.2 $C_{10}$ vs. $U_{10}F/v$, drag coefficient as a function of fetch Reynolds number

From a dimensional standpoint it would seem reasonable to have the velocity replaced by a dimensionless velocity parameter. There it proposed itself to consider an analogy between flow over a plate and airflow over a watersurface. For the flat plate the drag is given as:

$$C_f = f\left(\frac{U_{\infty}x}{v}, \frac{x}{k_s}\right)$$

with $U_{\infty}x/v$ as the local Reynolds number and $x/k_s$ as the relative roughness, where $U_{\infty}$ is the free stream velocity, $k_s$ is the equivalent sand roughness (expressed as $k_s = 30y_0$; $y_0$ being the roughness length) and $x$ is the distance from the leading edge.

Above relation is discussed in Schlichting ([14], Ch. XXI); it is given graphically on p. 611 and analytically for the smooth plate as:

$$C_f = \frac{1}{2}\left[2.0 \log \left(\frac{U_{\infty}x}{v}\right) - 0.65\right]^{-2.3}$$

and for the rough plate as:

$$C_f = \frac{1}{2}\left(2.87 + 1.58 \log \frac{x}{k_s}\right)^{-2.5}$$

or

$$C_f = \frac{1}{2}\left(0.54 + 1.58 \log \frac{x}{y_0}\right)^{-2.5}$$

By analogy we propose now for the air-flow over a watersurface with limited fetch a relation such as:

$$C_{10} = f\left(\frac{U_{10}F}{v}, \frac{F}{y_0}\right)$$

where $U_{10}$ is the velocity at 10 meters, $F$ is the fetch and $y_0$ is the roughness length.

The present data are plotted in form of above relationship in Fig. 4. Immediately it is noticed that the Leman data fall above the "smooth plate" curve. Furthermore, it seems that the Leman data are independent of the fetch Reynolds number, $U_{10}F/v$, and are only a function of the relative roughness, $F/y_0$. This implies that the water surface over the lake behaves hydraulically "completely rough". The present data show that an increase of the relative roughness, $F/y_0$, corresponds to an decrease of the drag coefficient, $C_{10}$, or
Aerodynamic Drag and Its Relation to the Sea State

Fig. 4. Drag coefficient, \( C_{10} \), versus fetch Reynolds number, \((U_{10}F)/v\); parameter is the relative roughness, \( F/\gamma_0 \); the Leman data

\[ C_{10} = 1/2 \left( -7.48 + 4.4 \log \frac{F}{\gamma_0} \right)^{-2.5} \]  

(15)

The numerical values in eqs. (15) and (13b) may be compared; obviously they should not be the same. To our knowledge the grouping of the parameters in eq. (14) has not been suggested as such before. However, there are certain indications which fall along our line of thinking. For example, Kraus [11] and Stewart [15] present fetch-data (see Fig. 5) on a plot of \( C_{10} \) versus \( U_{10} \). There is a clear tendency that with increasing fetch the drag coefficient increases as well. Yet another set of data presented in Kraus ([11], Fig. 3) is less conclusive. In Fig. 6 the Leman
Fig. 5. Drag coefficient, $C_{10}$, versus wind speed, $U_{10}$; limited fetch data a) after Kraus [11], b) after Stewart [15]; both compared with the least square fit line through the Leman data (---)

Fig. 6. Drag coefficient, $C_{10}$, versus wind speed, $U_{10}$; parameter is the effective fetch, $F$; the Leman data
Another parameter, related to the fetch, is the degree of wave development or wave age, given as $C/U_*$, with $C$ being the phase velocity of waves of a given amplitude. Kitaigorodskii ([8], p. 88) has shown a dependency between drag coefficient, $C_{10}$, and $C_0/U_*$, $C_0$ being here the phase velocity of the dominant wave. The initial stage of the wave development is indicated with very small $C_0/U_*$ values; at very large $C_0/U_*$ values the waves are practically fully developed. The former correspond to small fetches, while the latter is indicative for large fetches. Field data show that for increasing $C_0/U_*$ values the drag coefficient decreases. The same trend was also reported by Taylor et al. [16] and Davidson [2]; due to different definitions of $C_0$ a direct comparison is not possible. The Leman data are plotted in Fig. 7 and exhibit the same tendency. Again a comparison is impossible, since the used phase velocity, $C$, is the one of the significant wave, $H_{1/3}$.

To calculate $C$ an empirical relation for ocean data given by Wu [19] was used, or:

$$\frac{C}{U_{10}} = 0.05 \left( \frac{gF}{U_{10}^2} \right)^{0.30} \quad (16)$$

Finally, it should be mentioned that Plate et al. [13] have proposed a relation similar to eq. (14) to explain laboratory data.
3.3 $y_0$ vs. $H$, roughness length as a function of wave height

The Leman data lend themselves to study in a preliminary way a possible dependency of the roughness length, $y_0$, to a wave height parameter. For the present study only the significant wave height, $H_{1/3}$ (an average height of the largest one-third of waves) was calculated (and not measured); used was a relationship of

$$\frac{gH_{1/3}}{U_{10}^2} = 0.00305 \left( \frac{gF}{U_{10}^2} \right)^{0.466} \quad (17)$$

given by Wu [19] and established with field measurement of wind-generated ocean waves. A linear least square curve fit through the Leman data, plotted in Fig. 8, gives the relation:

$$\log y_0 = 0.0125 H_{1/3} - 3.83 \quad (18)$$

with $y_0$ and $H_{1/3}$ in cm and a coefficient of correlation of 0.6. Furthermore, there is indication that the wave age, expressed with $C/U_*$, classifies slightly the data.

The literature is evidently not abundant on this subject. Kitaigorodskii ([8], p. 29) plotted data from various investigators, using as wave height scale the mean square height of the waves, but found that no correlation is possible.
Dunckel et al. ([4], p. 89) showed, with only a limited data, that the drag coefficient increases with "the estimated wave height". In a subsequent study using the Jonswap II experiment, Krügermeyer et al. ([12], p. 407) reported an increase of the "significant wave height", $H_{1/3}$, with increasing wind speed; the latter data are compared with the linear least square curve fit through the Leman data in Fig. 9.

However, it must also be stated that Kondo et al. [9] found a very weak dependency between the wave height, $H_{1/3}$, and the wind speed, $U_{10}$, while "a representative scale of sea surface irregularities, $h_p$" (this is usually less than $1/100 H_{1/3}$) was found to increase with wind speed. This implies, according to Kondo et al. [9] and (still more recently) Plate et al. [13] that the mechanism of drag is controlled not by large waves but primarily by ripples and wavelets of high frequency which ride on top of the big waves.

In the light of the Leman data it would be appropriate to express the relative roughness as

$$y_0 = f \left( H, \frac{C}{U_w} \right)$$  \hspace{1cm} (19)

In a search through the literature, we found two relations of this type. Hsu [7] postulated a relation of:

$$y_0 = \frac{A}{2\pi} \left[ \frac{H}{(C/U_w)^2} \right]$$  \hspace{1cm} (20)

where $A$ is the coefficient to be determined and $H$ and $C$ are the height and celerity of the "dominant waves" (but it is not exactly clear what is meant). Hsu's relationship and the Leman data are compared in Fig. 10.

Kitaigorodskii [8] developed a relation of:

$$y_0 = B H e^{-\alpha U_s}$$  \hspace{1cm} (21)
where $B$ is a dimensionless numerical factor and $H_o e^{-k C_0 H_o}$ is the "normalized wave height" representing the height of the immobile wave roughness. In a rational but involved fashion the establishment of the normalized wave height is presented utilizing the statistical characteristic of the wave field, namely the frequency spectrum. Using a large amount of data, the relationship of the eq. (21) was established; it is reproduced in Fig. 11. The considerable spread of the data is indicated with point-dotted lines. On the same figure are plotted the Leman data. Comparing the two relations, one finds for the dimensionless numerical factors the values:

$$B_K = 0.12 \quad \text{for Kitaigorodskii's data}$$
$$B_L = 0.01 \quad \text{for the Leman data}$$

(22)
Fig. 11. Roughness length, $y_0$, versus wave height parameter after Kitaigorodskii [8], compared with the Leman data with a least square fit line (-----).

However, it must be realized that for the Leman data this factor is evaluated with the significant wave height, $H_{1/3}$, while the data of Kitaigorodskii ([8], p. 34) are for normalized waves whose height is "considerably smaller than mean-square height of the waves" and in effect depending upon the spectrum. If one realizes that the ratio of mean wave to significant wave height is theoretically given as: $H/H_{1/3} = 0.62$, then one finds the ratio between the two dimensionless numerical factors of eq. (22) – this is a type of ratio between "normalized" and "significant" waves $B_L/B_K = 0.08$ as a reasonable value.

4. Conclusions

With limited (and preliminary) data obtained on a lake it is shown that the fetch affects the aerodynamic drag. A dimensionless representation is given
with Fig. 4, where the proposed relation of \( C_{10} = f(U_{10}, F/F_v, F/F_0) \), is displayed. Furthermore an attempt is made to express the roughness length, \( y_0 \), as a function of a wave-parameter; it is given in a comparative way on Fig. 11.

References

Aerodynamic Drag and Its Relation to the Sea State


Authors' address: W. H. Graf and J. P. Prost, Laboratoire d'hydraulique, Ecole Polytechnique Fédérale, CH-1015 Lausanne, Switzerland.
No 38  Dragages lacustres et recul des rosellières
J. Bruschin et F. Klötzli

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W. H. Graf and V. H. Chhun
(tiré de: Journal of the Irrigation and Drainage Division, ASCE, IR4, 1976)

Ein mathematisches Wasser-Zirkulationsmodell für Sumpflandschaften
S. W. Bauer

No 41  Three-Dimensional Irregular-Grid Finite Difference Model of Wind Induced Water Level Fluctuations and Currents in a Homogeneous Lake with Applications to the Lake of Geneva
S. W. Bauer
(thèse No 335 EPFL, 1979)
Fondé en 1928 (1932), le Laboratoire d’hydraulique de l’Ecole Polytechnique Fédérale de Lausanne est le premier laboratoire d’Ecole créé à Lausanne. Depuis sa fondation jusqu’à une période récente, il s’est trouvé sous la direction des Profs. A. Stucky et D. Bonnard. Parmi les recherches entreprises, nous pouvons citer les suivantes : hydraulique des phénomènes instationnaires (chambres d’équilibre, branchements, vagues), mouvements d’alluvions (grains en suspension et formation des dépôts dans les retenues) et essais sur modèles (barrages, évacuateurs de crues, bassins amortisseurs, etc.).

Depuis 1974, le centre de gravité de nos recherches s’est porté plus spécialement sur : les écoulements biphasiques, l’hydrodynamique des lacs, l’hydrologie des événements extrêmes et les techniques de modélisation.

Au service de l’enseignement, de l’Etat et de l’industrie privée, le Laboratoire d’hydraulique poursuit un triple objectif : (1) fournir un équipement adéquat à l’enseignement et un matériel permettant aux diplômés et doctorants d’effectuer leurs recherches; (2) augmenter au moyen de la recherche les connaissances en hydraulique et améliorer la formation et l’expérience du personnel de recherche; (3) assumer avec l’équipement et le savoir-faire dont il dispose, le rôle d’expert dans les secteurs public et privé et rendre ainsi des services importants à l’économie du pays.

Das im Jahre 1928 (1932) gegründete Hydraulik-Laboratorium der Eidgenössischen Technischen Hochschule in Lausanne ist das erste Ingenieur-Laboratorium, welches man in Lausanne einrichtete. Seit seiner Gründung stand es unter der Leitung von Prof. A. Stucky und Prof. D. Bonnard. Zu den verschiedenen durchgeführten wissenschaftlichen Arbeiten zählen unter anderem: Hydraulik von nichtstationären Problemen (Wasserschlosser, Rohrverzweigungen und Wellenhydraulik); Feststoff-Transport (Suspensionstracht und Stauraumveränderung), und Modellhydraulik (Dämme, Entlastungsanlagen, Sturzbecken, etc.).


In seinem Dienste im Rahmen von Erziehung, Staat und Industrie erfüllt das "Laboratoire d’hydraulique" eine dreifache Aufgabe : (1) Die Laboreinrichtungen werden im Lehrbetrieb für Studenten und Doktoranden verwendet; (2) durch die Forschung werden neue Erkenntnisse gewonnen und wissenschaftlichen Mitarbeitern die Möglichkeit zur Weiterbildung gegeben; (3) mit seinen Anlagen und Instrumenten ist das Laboratorium von großer Bedeutung für Auftragsforschung und Beratung von öffentlichen und privaten Personen und dadurch wichtig für einen großen Sektor der Schweizer Industrie.

Founded in 1928 (1932), the Hydraulics Laboratory of the Federal Institute of Technology in Lausanne was the first engineering laboratory instituted at Lausanne. Since its foundation it was under the directorship of Profs. A. Stucky and D. Bonnard. Among the research done, the following may be named: Hydraulics of Nonsteady Phenomena (surge tanks, pipe junctions and waves), Sediment Research (suspended load and reservoir sedimentation) and Hydraulic Models (dams, spillways, stilling basins, etc.).


In its service to education, to the government and to industry, the "Laboratoire d'hydraulique" has a 3-fold objective: (1) It provides laboratory facilities for teaching purposes and means by which students and doctorands can pursue their research; (2) through research itself knowledge is extended while staff members obtain further training and experience; (3) with its unique equipments and facilities it is of great importance for public and private counseling and thus very important for a viable sector of the Swiss economy.

Creado en 1928 (1932), el Laboratorio de hidráulica de la Escuela Politécnica Federal de Lausanne fue el primer laboratorio en ese campo en Lausanna. Desde su fecha de fundación hasta un período reciente, se encontró bajo la dirección de los Profs. A. Stucky y D. Bonnard. Dentro de las investigaciones adelantadas, podemos citar las siguientes: hidráulica de los fenómenos no estacionarios (cámara de equilibrio, conexiones, olas), movimientos de aluviones (granos en suspensión y formación de depósitos en las retenciones) y ensayos sobre módelos (represas, evacuador de crecidas, cámara de equilibrio, etc.).

Desde 1974, el centro de gravedad de nuestras investigaciones se concentró más especialmente sobre: la hidrología de los eventos extremos y las técnicas de modelización.

Al servicio de la docencia, del Estado y de la industria privada, el Laboratorio de hidráulica persigue tres objetivos: (1) suministrar un equipo adecuado a la docencia y un material que permite a los diplomados y a los asistentes preparando una tesis de doctorado, de hacer sus investigaciones; (2) aumentar, por medio de la investigación, los conocimientos en hidráulica y mejorar la formación y la experiencia del personal vinculado al Laboratorio; (3) asumir, con el equipo y el saber-hacer del cual se dispone, el papel de experto en los sectores publico y privado, y prestar así de importantes servicios a la economía del país.