Lift and Drag

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1 Introduction

Maybe already twenty years ago the question was raised to what extend lift or drag forces propelled the rowing boat. See e.g. the German publication of Volker Nolte: “Wie wird ein Ruderboot angetrieben? Theoretische Konzepte bestimmen die Methodik der Rudertechnik”, Leistungssport #6, 1984. The subject was also discussed in relation to swimming (Ross Sanders and Edith Cowan) and canoeing. The idea of Nolte was that the modern rowing style was based on the use of the lift force as the main propulsive force in rowing in the early phase of the drive. However, in rowing the blade has fewer degrees of freedom than in swimming and canoeing. About the only thing a rower can do is reaching further at the catch and that is recommended by coaches who believe in the benefits of the lift force. Below the nature of lift and drag will be explained, set in perspective and lift and drag coefficients are presented.

2 Basics of lift and drag

When a solid body is placed in a fluid flow and a nonsymmetrical situation occurs the direction of the force on the body does not coincide with the direction of the (undisturbed) flow. This principle makes flying possible. Discussion of lift and drag starts usually with the introduction of an airfoil. (x is the direction of the horizontal flow, z is vertical)

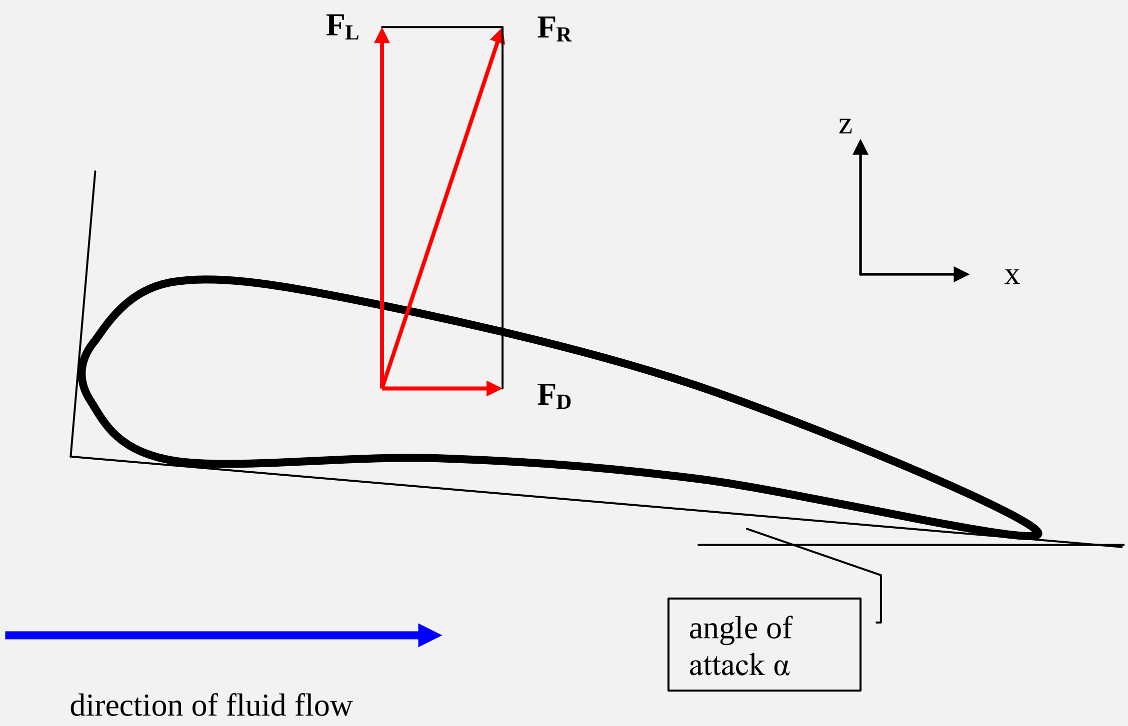

Fig 2.1
Forces on an airfoil

The airfoil (e.g. the cross section of an airplane wing) is long in the direction perpendicular to the plane of the drawing and the flow can be considered as two dimensional. The airfoil is tilted with respect to the (undisturbed) flow direction, defined by the angle of attack, AOA, α. the airfoil experiences a force F_R. Considering an airplane it is very useful to decompose the force F_R into components F_L and F_D perpendicular and parallel to the flow direction. F_L is the lift force, it carries the plane, and by definition **it does not do work**. F_D is the drag force, the resistance to be balanced by the propulsion force generated by the engines. The net power required is the product of drag force times flow velocity. The lift and drag forces are expressed as:

$$F_L = 0.5 C_L \rho A u^2$$

$$F_D = 0.5 C_D \rho A u^2$$

with:
F_L and F_D = lift and drag force
C_L = lift coefficient
C_D = drag coefficient
ρ = density of the fluid
A = reference area
u = velocity of the undisturbed flow

Note that the expression for F_L and F_D differ only in C_L and C_D. The designer of an airplane tries to maximize C_L and to minimize C_D. C_L and C_D are dependent on the angle of attack. For an enormous number of airfoil profiles C_L and C_D have been measured or calculated. Usually the C_L drops sharply and C_D increases strongly at α = abt.15^0. The force on the airfoil is the result of the integration of pressure around the perimeter.

When not an airfoil but a flat surface with zero thickness is placed in a flow a lift and drag force can be distinguished as well.

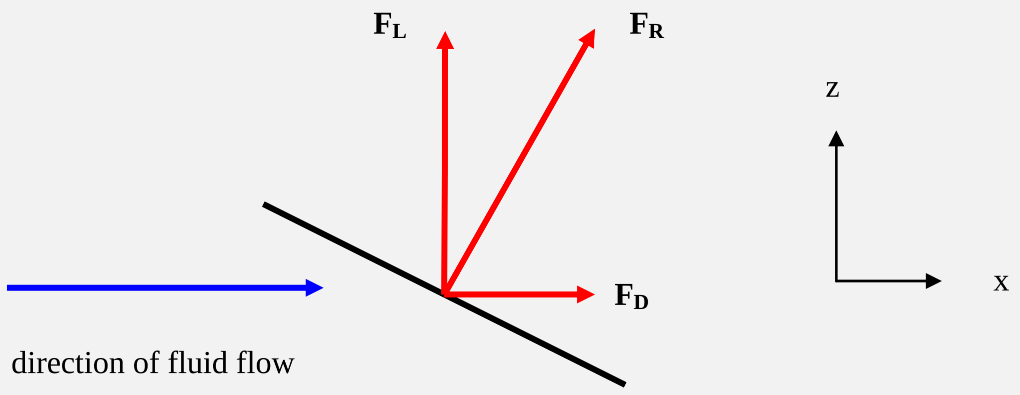

Fig 2.2
Forces on a flat surface

As the force is the resultant of the pressure on the surface the direction of the force cannot be different from perpendicular to the surface (shear forces neglected). This includes that C_D and C_L cannot be independent of each other. Between the two the next relation exists:

$$\frac{C_D}{C_L} = \tan\alpha$$

When a curved surface with zero thickness is placed in a flow the force on every surface element is perpendicular to that element but as the angle of attack varies and also the pressure distribution not much can be said about the position and the direction of the resulting force. See Fig 2.3. But when the curvature is small as with a rowing blade, the situation cannot be very different from a flat plate. Assume now that the forces are in the horizontal plane as is the case with rowing. For an elaboration of the idea see section **5. C_D and C_L as function of the angle of attack.**

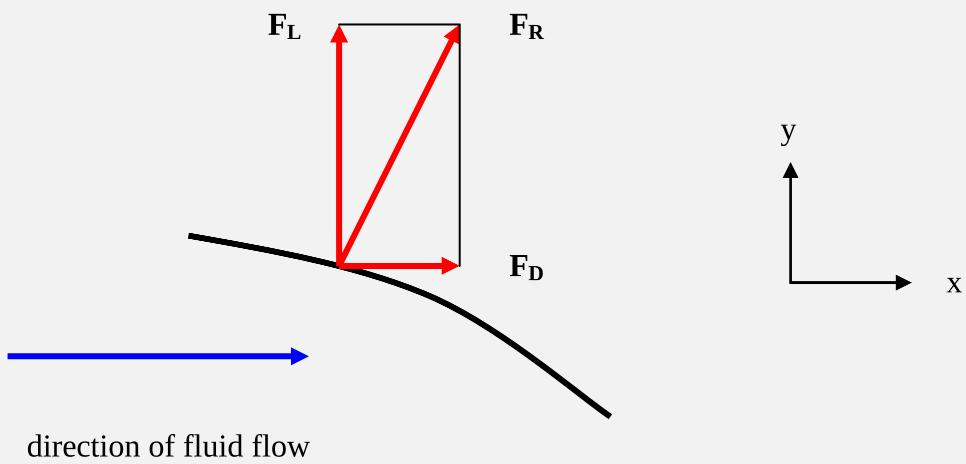

Fig 2.3
Forces on a curved surface

From the explanation above follows:
The distinction between lift and drag is not of a physical nature but it is a functional one (carrying and resisting) or a geometrical one (perpendicular and parallel to the flow direction) but the observation made before that the lift force does not do work is of importance. In other words, the lift force does not waste energy.

3 Kinematics of the blade

Fig 3.1 shows the velocities of the boat and the oar/scull.

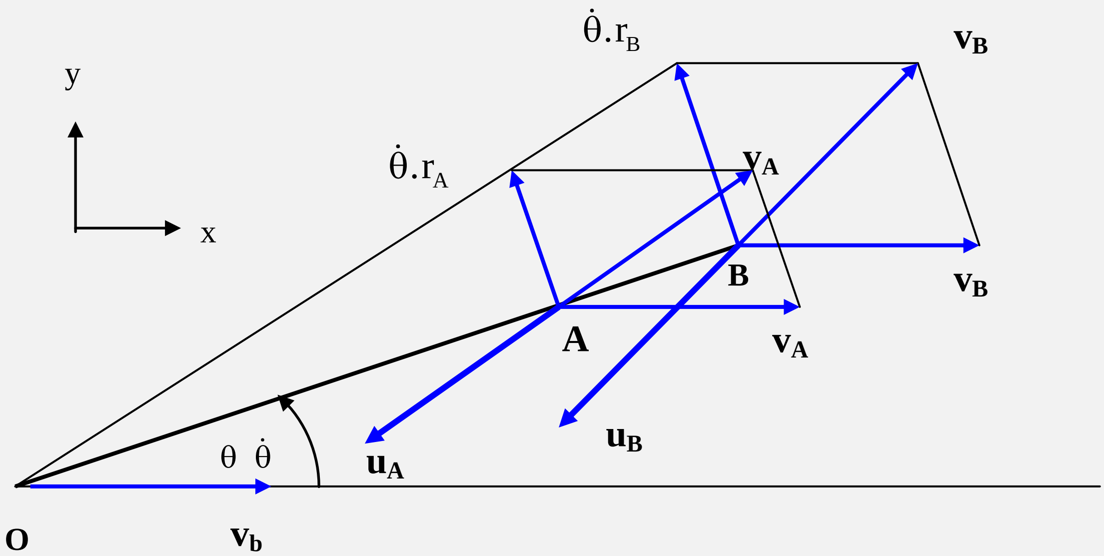

Fig 3.1
Kinematics

O = pin
OA = shaft of the oar/scull, situation immediately after the catch
AB = blade
v_b = boat velocity
θ = angle between shaft of the oar/scull and longitudinal axis of the boat
$\dot{\theta}$ = angular velocity of oar/scull
r_A = distance OA
r_B = distance OB

We arrived now at a situation as described in section 2. In the next section we shall continue our discussion on the description of the interaction between water and blade.

4 Blade-flow interaction

Consider the situation in Fig 4.1. A curved surface, the blade, in a flow. The figure is a combination of elements from Fig 2.3 and Fig 3.1.

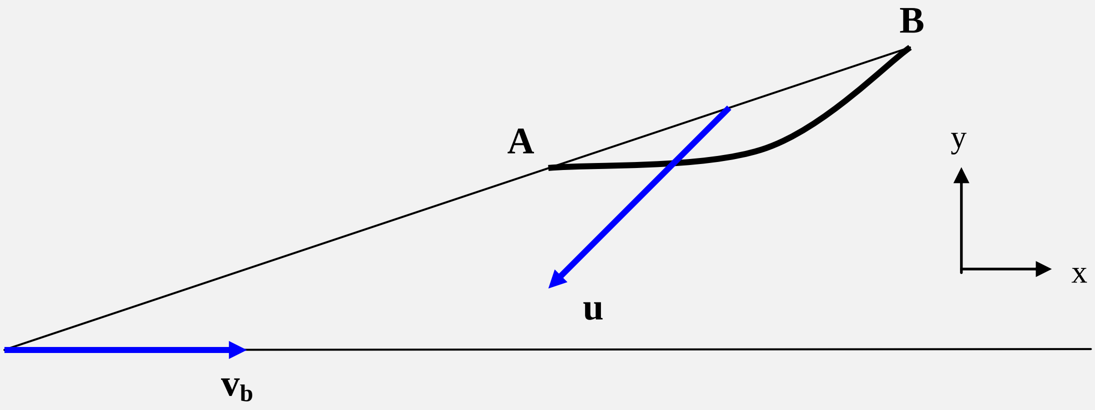

Fig 4.1
Blade in the flow

Important differences with the situations described in section 2 exist. The system is not two-dimensional, the object is very close to the air-water interface, the velocity field is not homogeneous and the situation changes rapidly with time. Another complication is that at the whole convex side of the blade the water is in turbulence. All these complications will be neglected in the following discussion and the blade is considered flat as stated before.

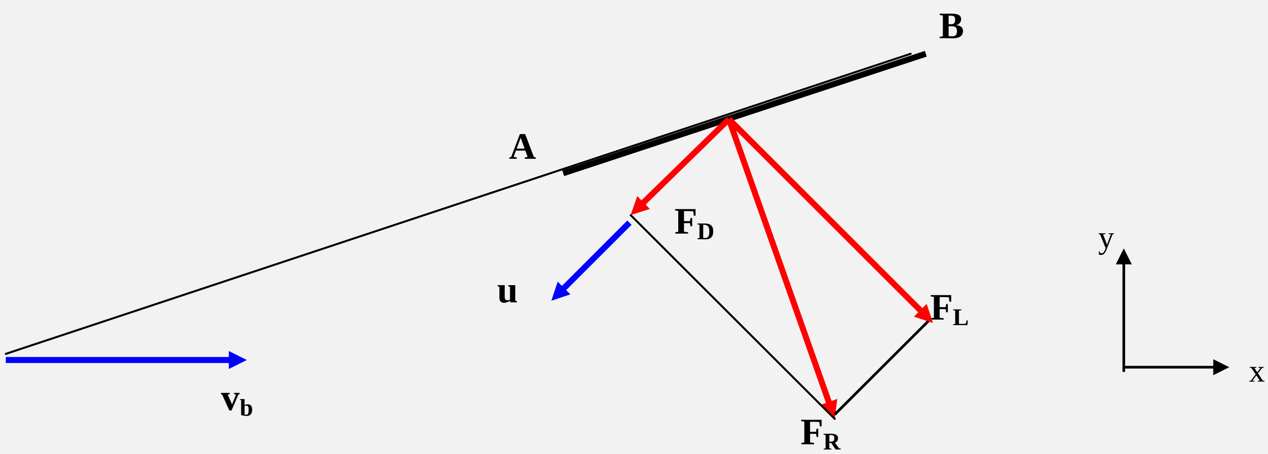

Fig 4.2
Force on the blade

In Fig 4.2 the force on the blade due to the flow according to Fig 4.1 has been drawn. As demonstrated in section 2, the resulting force F_R is perpendicular to the blade. (It is a weak argument but I think that when I am rowing I “feel” a force perpendicular to the blade). Of course F_R can be decomposed in a lift and a draft force F_L and F_D.
(Also a lift force in the vertical direction exists. This is the force that prevents the blade from diving to deep into the water and facilitates the extraction of the blade at the end of the drive. It does not contribute to the propulsion)
Otherwise than in the case of a wing of an airplane the direction of the lift and drag force has no functional meaning. They can be decomposed again in a transverse and a longitudinal direction as has been done by the Dreissigacker brothers (FISA Coaches Conference, Sevilla 2000). But this is a rather indirect approach. The same result is obtained by decomposing F_R directly in its transverse and longitudinal components. See Fig 4.3.

Fig 4.3
F_D and F_L or F_R decomposed in transverse and longitudinal components.
Situation at the catch.

In this situation the force on the blade is mainly a lift force that does not waste energy but unfortunately the longitudinal component that propels the boat is very small. In swimming or canoeing the "blade" has more degrees of freedom. The blade can turned in such a way that the longitudinal component is greater. The only possibility to influence the direction of the lift force is to change the position of the blade with respect to the shaft which is not possible with normal rowing equipment.
Turning the blade with respect to the shaft as in Fig 4.4 might be attractive.
The force on the blade becomes more effective. However, the angle of attack becomes smaller and that is a drawback. This can be compensated by a bigger rotational speed of the oar. The effect will be positive only in the first phase of the drive and negative in the last phase but the net effect could be positive.
Turning the blade is this way has been proposed before by M.N. Brearley ("Modeling the rowing stroke in racing shells", The Mathematical Gazette, Nov 1998). His estimate of the gain is not correct and this blade-shaft configuration was never (?) seen during a regatta.

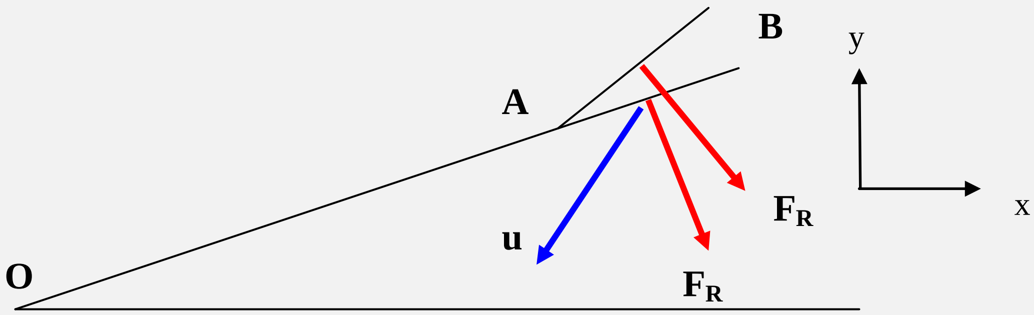

Fig 4.4
The effect of turning the blade on the direction of the force.

5 C_D and C_L as function of the angle of attack.

Recently new experiments were carried out to determine the hydrodynamic coefficients for rowing blades. See:
Journal of Sports Sciences, April 2007; 25(6): 643-650
Nicholas Caplan & Trevor N. Gardner,
"A fluid dynamic investigation of the Big Blade and Macon oar blade designs in rowing propulsion"

The following expression for C_D and C_L has been derived from the results in this paper but are the interpretation of this author:

$$C_D = 2 C_{L\,max} (\sin\alpha)^2$$

$$C_L = C_{L\,max} \sin(2\alpha)$$

These expressions fulfil the requirement

$$\frac{C_D}{C_L} = \tan\alpha$$

Caplan and Gardner found values $C_{Lmax} \approx 1.2$ for a flat plate *and* for a hatchet blade. This results in C_D values of 2.4. This is more than found in the literature. Therefore in our calculations we use maximum values of 2.0 and 1.0 for drag and lift respectively.

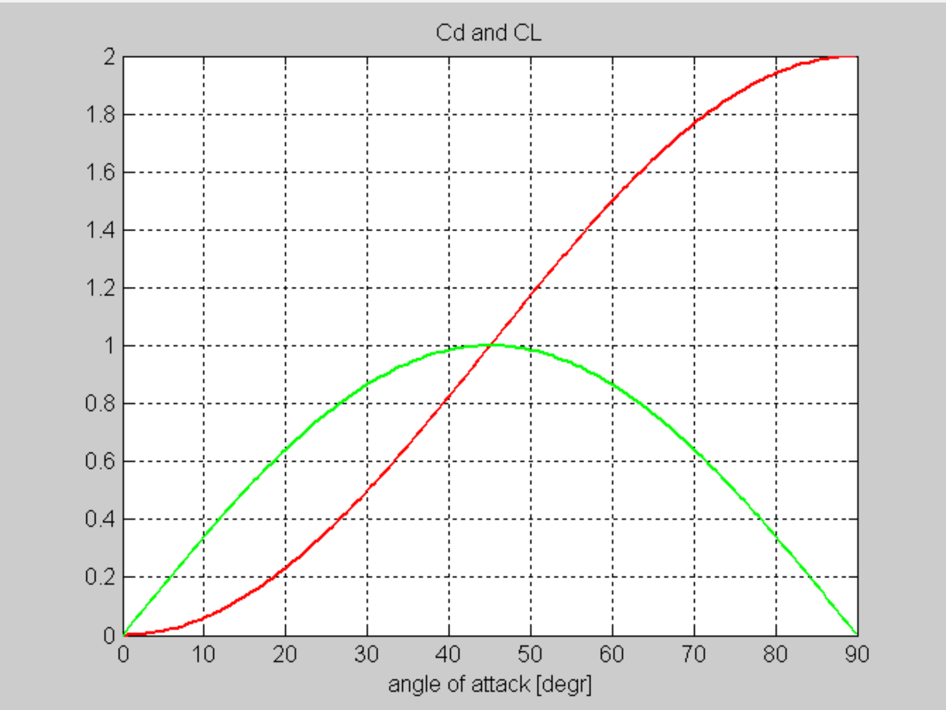

Fig 5.1
CD, red and CL, green according to Caplan and Gardner (modified).

See also Atkinson who discusses in more detail the results of Caplan and Gardner. The smooth functions for the coefficients are an advantage for the simulation because of the iterations it contains. It is hoped that some hydrodynamic scientist will comment on the validity of the coefficients in the future.

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