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Resistance

Section 1
Introduction

1.1 The Problem. A ship differs from any other large engineering structure in that—in addition to all its other functions—it must be designed to move efficiently through the water with a minimun of external assistance. In Chapters I-III of Vol. I it has been shown how the naval architect can ensure adequate buoyancy and stability for a ship, even if damaged by collision, grounding, or other cause. In Chapter IV the problem of providing adequate structure for the support of the ship and its contents, both in calm water and rough seas, was discussed.

In this chapter we are concerned with how to make it possible for a structure displacing up to 500,000 tonnes or more to move efficiently across any of the world's oceans in both good and bad weather. The problem of moving the ship involves the proportions and shape—or form—of the hull, the size and type of propulsion plant to provide motive power, and the device or system to transform the power into effective thrust. The design of power plants is beyond the scope of this[1] book (see *Marine Engineering*, by R.L. Harrington, Ed., SNAME 1971). The nine sections of this chapter will deal in some detail with the relationship between hull form and resistance to forward motion (or drag). Chapter VI discusses propulsion devices and their interaction with flow around the hull.

The task of the naval architect is to ensure that, within the limits of other design requirements, the hull form and propulsion arrangement will be the most efficient in the hydrodynamic sense. The ultimate test is that the ship shall perform at the required speed with the minimum of shaft power, and the problem is to attain the best combination of low resistance and high propulsive efficiency. In general this can only be attained by a proper matching of hull and propeller.

Another factor that influences the hydrodynamic design of a ship is the need to ensure not only good smooth-water performance but also that under average service conditions at sea the ship shall not suffer from excessive motions, wetness of decks, or lose more speed than necessary in bad weather. The assumption that a hull form that is optimum in calm water will also be optimum in rough seas is not necessarily valid. Recent research progress in oceanography and the seakeeping qualities of ships has made it possible to predict the relative performance of designs of varying hull proportions and form under different realistic sea conditions, using both model test and computing techniques. The problem of ship motions, attainable speed and added power requirements in waves are discussed in Chapter VIII, Vol. III. This chapter is concerned essentially with designing for good smooth-water performance.

Another consideration in powering is the effect of deterioration in hull surface condition in service as the result of fouling and corrosion and of propeller roughness on resistance and propulsion. This subject is discussed in this chapter.

As in the case of stability, subdivision, and structure, criteria are needed in design for determining acceptable levels of powering. In general, the basic contractual obligation laid on the shipbuilder is that the ship shall achieve a certain speed with a specified power in good weather on trial, and for this reason smooth-water performance is of great importance. As previously noted, good sea performance, particularly the maintenance of sea speed, is often a more important requirement, but one that is much more difficult to define. The effect of sea condition is customarily allowed for by the provision of a service power margin above the power required in smooth water, an allowance which depends on the type of ship and the average weather on the sea routes on which the ship is designed to operate. The determination of this service allowance depends on the accumulation of sea-performance data on similar ships in similar trades. Powering criteria in the form of conventional service allowances for both

[1] Complete references are listed at end of chapter.

sea conditions and surface deterioration are considered in this chapter.

The problem of controlling and maneuvering the ship will be covered in Chapter IX, Vol. III.

1.2 Types of Resistance. The resistance of a ship at a given speed is the force required to tow the ship at that speed in smooth water, assuming no interference from the towing ship. If the hull has no appendages, this is called the bare-hull resistance. The power necessary to overcome this resistance is called the towrope or effective power and is given by

$$P_E = R_T V \tag{1a}$$

where P_E = effective power in kWatt (kW)
R_T = total resistance in kNewton (kN)
V = speed in m/sec

$$\text{or ehp} = R_T V_k / 326 \tag{1b}$$

where ehp = effective power in English horsepower
R_T = total resistance in lb
V_k = speed in knots

To convert from horsepower to S.I. units there is only a slight difference between English and metric horsepower:

hp (English) × 0.746 = kW
hp (metric) × 0.735 = kW
Speed in knots × 0.5144 = m/sec

This total resistance is made up of a number of different components, which are caused by a variety of factors and which interact one with the other in an extremely complicated way. In order to deal with the question more simply, it is usual to consider the total calm water resistance as being made up of four main components.

(a) The frictional resistance, due to the motion of the hull through a viscous fluid.

(b) The wave-making resistance, due to the energy that must be supplied continuously by the ship to the wave system created on the surface of the water.

(c) Eddy resistance, due to the energy carried away by eddies shed from the hull or appendages. Local eddying will occur behind appendages such as bossings, shafts and shaft struts, and from stern frames and rudders if these items are not properly streamlined and aligned with the flow. Also, if the after end of the ship is too blunt, the water may be unable to follow the curvature and will break away from the hull, again giving rise to eddies and separation resistance.

(d) Air resistance experienced by the above-water part of the main hull and the superstructures due to the motion of the ship through the air.

The resistances under *(b)* and *(c)* are commonly taken together under the name residuary resistance. Further analysis of the resistance has led to the identification of other sub-components, as discussed subsequently.

The importance of the different components depends upon the particular conditions of a design, and much of the skill of naval architects lies in their ability to choose the shape and proportions of hull which will result in a combination leading to the minimum total power, compatible with other design constraints.

In this task, knowledge derived from resistance and propulsion tests on small-scale models in a model basin or towing tank will be used. The details of such tests, and the way the results are applied to the ship will be described in a later section. Much of our knowledge of ship resistance has been learned from such tests, and it is virtually impossible to discuss the various types of ship resistance without reference to model work.

1.3 Submerged Bodies. A streamlined body moving in a straight horizontal line at constant speed, deeply immersed in an unlimited ocean, presents the simplest case of resistance. Since there is no free surface, there is no wave formation and therefore no wave-making resistance. If in addition the fluid is assumed to be without viscosity (a "perfect" fluid), there will be no frictional or eddymaking resistance. The pressure distribution around such a body can be determined theoretically from considerations of the potential flow and has the general characteristics shown in Fig. 1(*a*).

Near the nose, the pressure is increased above the hydrostatic pressure, along the middle of the body the pressure is decreased below it and at the stern it is again increased. The velocity distribution past the hull, by Bernoulli's Law, will be the inverse of the pressure distribution—along the midportion it will be greater than the speed of advance V and in the region of bow and stern it will be less.

Since the fluid has been assumed to be without viscosity, the pressure forces will everywhere be normal to the hull (Fig. 1(*b*)). Over the forward part of the hull, these will have components acting towards the stern and therefore resisting the motion. Over the after part, the reverse is the case, and these components are assisting the motion. It can be shown that the resultant total forces on the fore and after bodies are equal, and the body therefore experiences no resistance.[2]

In a real fluid the boundary layer alters the virtual shape and length of the stern, the pressure distribution there is changed and its forward component is reduced. The pressure distribution over the forward portion is but little changed from that in a perfect fluid. There is therefore a net force on the body acting against the motion, giving rise to a resistance which is variously referred to as form drag or viscous pressure drag.

In a real fluid, too, the body experiences frictional resistance and perhaps eddy resistance also. The fluid immediately in contact with the surface of the body is

[2] This was first noted by the French mathematician d'Alembert in 1744, and is known as d'Alembert's paradox.

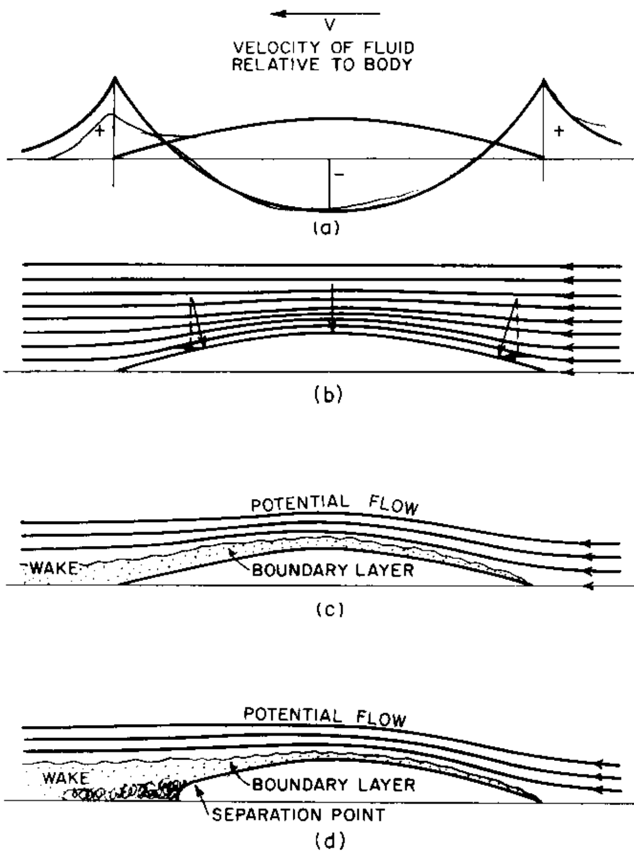

Fig. 1 Examples of flow about a submerged body

carried along with the surface, and that in the close vicinity is set in motion in the same direction as that in which the body is moving. This results in a layer of water, which gets gradually thicker from the bow to the stern, and in which the velocity varies from that of the body at its surface to that appropriate to the potential flow pattern (almost zero for a slender body) at the outer edge of the layer (Fig. 1(*c*)). This layer is called the boundary layer, and the momentum supplied to the water in it by the hull is a measure of the frictional resistance. Since the body leaves behind it a frictional wake moving in the same direction as the body (which can be detected far astern) and is continually entering undisturbed water and accelerating it to maintain the boundary layer, this represents a continual drain of energy. Indeed, in wind-tunnel work the measurement of the velocities of the fluid behind a streamlined model is a common means of measuring the frictional drag.

If the body is rather blunt at the after end, the flow may leave the form at some point—called a *separation point*—thus reducing the total pressure on the afterbody and adding to the resistance. This *separation resistance* is evidenced by a pattern of eddies which is a drain of energy (Fig. 1(*d*)).

1.4 Surface Ships. A ship moving on the surface of the sea experiences frictional resistance and eddy-making, separation, and viscous pressure drag in the same way as does the submerged body. However, the presence of the free surface adds a further component. The movement of the hull through the water creates a pressure distribution similar to that around the submerged body; i.e., areas of increased pressure at bow and stern and of decreased pressure over the middle part of the length.

But there are important differences in the pressure distribution over the hull of a surface ship because of the surface wave disturbance created by the ship's forward motion. There is a greater pressure acting over the bow, as indicated by the usually prominent bow wave build-up, and the pressure increase at the stern, in and just below the free surface, is always less than around a submerged body. The resulting added resistance corresponds to the drain of energy into the wave system, which spreads out astern of the ship and has to be continuously recreated. (See Section 4.3). Hence, it has been called wave-making resistance. The result of the interference of the wave systems originating at bow, shoulders (if any) and stern is to produce a series of divergent waves spreading outwards from the ship at a relatively sharp angle to the centerline and a series of transverse waves along the hull on each side and behind in the wake (Fig. 7).

The presence of the wave systems modifies the skin friction and other resistances, and there is a very complicated interaction among all the different components.