**<u>Questão 1</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the problem of moving the ship involves the following, EXCEPT:**

(a) Proportions and shape of the hull

(b) The size of the propulsion plant

(c) The type of the propulsion plant

(d) The system to transform the power into effective thrust

(e) The speed of the ship

**Questão 1 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 1. **Página 1.**

**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.

**<u>Questão 2</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the best combination of low resistance and high propulsive efficiency, in general can only be attained by:**

(a) A proper matching of hull and propeller.

(b) A proper matching of engine and propeller.

(c) A proper matching of hull and engine.

(d) A proper matching of hull and appendages.

(e) A proper matching of propeller and appendages.

**Questão 2 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 1. **Página 1.**

> 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.

**Questão 3** – **According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), analyze the affirmatives below and choose the CORRECT answer:**

**I – A factor that influences the hydrodynamic design of a ship is the need to ensure not only good smooth-water performance but also that under extreme service conditions at sea the ship shall not suffer from excessive motions, wetness of decks, or lose more speed than necessary in bad weather.**

**II – The assumption that a hull form that is optimum in calm water will also be optimum in rough seas is likewise valid.**

**III – A good sea performance, particularly the maintenance of sea speed, is often a more important requirement.**

**IV – 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.**

(a) All are true.

(b) Only II and III are true.

(c) Only I and II are true.

(d) Only III and IV are true.

(e) Only I, III and IV are true.

**Questão 3 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 1. **Página 1.**

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

**<u>Questão 4</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), what resistances are commonly taken together under the name residuary resistance:**

(a) Frictional and wave-making

(b) Wave-making and eddy resistance

(c) Wave-making, eddy resistance and air resistance

(d) Air resistance and eddy resistance

(e) Air resistance and wave-making

**Questão 4 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 1. **Página 2.**

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.

**<u>Questão 5</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), it is usual to consider the total calm water resistance as being made up of four main components. That being said, regarding those four components, analyze the affirmatives below and choose that is NOT one of them:**

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

(b) The wave-making resistance is 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 is 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.

(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.

(e) Wind resistance experienced by the above-water part of the main hull and the superstructures due to the air motion.

**Questão 5 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 1. **Página 2.**

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.

**<u>Questão 6</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), um corpo perfeitamente hidrodinâmico, navegando bem submerso em um oceano ilimitado (fluido real), podemos afirmar que esse corpo terá:**

(a) Apenas a resistência de ondas

(b) Apenas a resistência friccional

(c) Apenas a resistência de vórtices

(d) Apenas a resistência friccional e de vórtices

(e) Nenhuma resistência

**Questão 6 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 1. **Página 2.**

**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).

**Questão 7 – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), em um fluido real, a camada limite altera o formato e o comprimento da popa virtualmente, a distribuição de pressões é modificada e a componente da pressão para vante é reduzida. A distribuição de pressões na parte de vante é pouco mudada em relação a situação de fluido perfeito. Essa cadeia de forças que age contra o movimento do navio é chamada de:**

(a) Frictional resistance

(b) Eddy resistance

(c) Separation resistance

(d) Form drag

(e) Parasite drag

**Questão 7 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 1. **Página 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.

**<u>Questão 8</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), a quantidade de movimento fornecido pelo casco à camada limite é uma medida da:**

(a) Parasite drag

(b) Eddy resistance

(c) Separation resistance

(d) Form drag

(e) Frictional resistance

**Questão 8 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 1. **Página 3.**

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 contin-

**<u>Questão 9</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding resistance of surface ships, analyze the affirmatives below and choose the INCORRECT answer:**

(a) A ship moving on the surface of the sea experiences frictional resistance and eddymaking, separation, and viscous pressure drag in the same way as does the submerged body.

(b) There are no important differences in the pressure distribution over the hull of a surface ship caused by surface wave disturbance created by the ship's forward motion.

(c) 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.

(d) 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.

(e) 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.

**Questão 9 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 1. **Página 3.**

**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.

**<u>Questão 10</u> – One has only to look down from the deck of a ship at sea and observe the turbulent motion in the water near the hull, increasing in extent from bow to stern, to realize that energy is being absorbed. According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), that drain of energy is given by:**

(a) Only frictional resistance

(b) Only frictional resistance and eddy resistance

(c) Only frictional resistance, wave-making resistance and eddy resistance

(d) Only frictional resistance and wave-making resistance

(e) All types of resistance

**Questão 10 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 3. **Página 7.**

**3.1 General** One has only to look down from the deck of a ship at sea and observe the turbulent motion in the water near the hull, increasing in extent from bow to stern, to realize that energy is being absorbed in frictional resistance. Experiments have shown that even in smooth, new ships it accounts for 80 to 85 percent of the total resistance in slow-speed ships and as much as 50 percent in high-speed ships. Any rough ness of the surface will increase the frictional resist ance appreciably over that of a smooth surface, and with subsequent corrosion and fouling still greater increases will occur. Not only does the nature of the surface affect the drag, but the wake and propulsive performance are also changed. Frictional resistance is thus the largest single component of the total resist ance of a ship, and this accounts for the theoretical and experimental research that has been devoted to it over the years. The calculation of wetted surface area which is required for the calculation of the frictional resistance, Equation (11), is discussed in Chapter I.

**<u>Questão 11</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre a resistência friccional, analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:**

**I – Para qualquer condição, 80 a 85% da resistência total é composta por resistência friccional em baixas velocidades.**

**II – Para navios novos e com cascos lisos, 50% em altas velocidades.**

**III – Qualquer rugosidade aumentará a resistência friccional apreciavelmente, e com consequente corrosão e incrustação ainda maiores aumentos ocorrerão.**

**IV – A natureza da superfície afeta resistência, mas não altera a esteira e a performance propulsiva.**

(a) Todas são verdadeiras.

(b) Apenas I, II e III são verdadeiras.

(c) Apenas II e III são verdadeiras.

(d) Apenas I, III e IV são verdadeiras.

(e) Apenas II e IV são verdadeiras.

**Questão 11 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 3. **Página 7.**

**3.1 General** One has only to look down from the deck of a ship at sea and observe the turbulent motion in the water near the hull, increasing in extent from bow to stern, to realize that energy is being absorbed in frictional resistance. Experiments have shown that even in smooth, new ships it accounts for 80 to 85 percent of the total resistance in slow-speed ships and as much as 50 percent in high-speed ships. Any rough ness of the surface will increase the frictional resist ance appreciably over that of a smooth surface, and with subsequent corrosion and fouling still greater increases will occur. Not only does the nature of the surface affect the drag, but the wake and propulsive performance are also changed. Frictional resistance is thus the largest single component of the total resist ance of a ship, and this accounts for the theoretical and experimental research that has been devoted to it over the years. The calculation of wetted surface area which is required for the calculation of the frictional resistance, Equation (11), is discussed in Chapter I.

**Questão 12** – **According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding Froude's formulation ($R = f.S.V^n$) for frictional resistance, analyze the affirmatives below and choose the CORRECT answer:**

**I – The specific resistance per unit of surface area was less for a long plank than for a shorter one.**

**II – *f* and *n* depend on length and nature of surface.**

**III – For the smooth varnished surface, the value of the exponent *n* decreased from 2.0 for the short plank to 1.83 for the 15.2 m (50 ft) plank. For the planks roughened by sand, the exponent had a constant value of 2.0.**

**IV – For a given type of surface, the *f* value decreased with increasing length, and for a given length it increased with surface roughness.**

(a) All are true.

(b) Only I, II and III are true.

(c) Only II, III and IV are true.

(d) Only I and II are true.

(e) Only III and IV are true.

**Questão 12 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 3. **Páginas 7 e 8.**

**Página 7.**

The planks varied in lengths from 0.61 m (2 ft) to 15.2 m (50 ft) and the speed range covered was from 0.5 m/sec (1.67 fps) to 4.1 m/sec (13.3 fps), the maximum for the 15.2 m plank being 3.3 m/sec (10.8 fps). Froude found that at any given speed the specific resistance per unit of surface area was less for a long plank than for a shorter one, which he attributed to the fact that towards the after end of the long plank the water had acquired a forward motion and so had a lower relative velocity.

He gave an empirical formula for the resistance in the form

$$R = fSV^n \qquad (14)$$

where $R$ = resistance, kN or lb $S$ = total area of surface, $m^2$ or $ft^2$ $V$ = speed, m/sec or ft/sec

**Página 8.**

$f$ and $n$ depended upon length and nature of surface, and are given in Table 1.

For the smooth varnished surface, the value of the exponent $n$ decreased from 2.0 for the short plank to 1.83 for the 15.2 m (50 ft) plank. For the planks roughened by sand, the exponent had a constant value of 2.0.

For a given type of surface, the $f$ value decreased with increasing length, and for a given length it increased with surface roughness.

**Questão 13** – **According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), analyze the affirmatives below and choose the CORRECT answer:**

**I – At a length of 50 feet, the decrease, with increasing length, of the friction per square foot of every additional length is so small that it will make no very great difference in our estimate of the total resistance of a surface 300 ft long whether we assume such decrease to continue at the same rate throughout the last 250 feet of the surface, or to cease entirely after 50 feet.**

**II – The actual ship resistance was everywhere higher than that predicted from the model, the percentage increase becoming higher with increasing speed.**

**III – The difference in $R/V^2$, however, is almost the same at all speeds, except the lowest.**

**IV – The difference in $R/V^2$ increases only slowly with increasing speed, as might occur if this additional resistance were of viscous type and varying at some power less than the second.**

(a) All are true.

(b) Only I and III are true.

(c) Only II and IV are true.

(d) Only I, II and III are true.

(e) Only III and IV are true.

**Questão 13 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 3. **Página 8.**

$f$ and $n$ depended upon length and nature of surface, and are given in Table 1.

For the smooth varnished surface, the value of the exponent $n$ decreased from 2.0 for the short plank to 1.83 for the 15.2 m (50 ft) plank. For the planks roughened by sand, the exponent had a constant value of 2.0.

For a given type of surface, the $f$ value decreased with increasing length, and for a given length it increased with surface roughness.

In order to apply the results to ships, the derived skin-friction coefficients had to be extrapolated to much greater lengths and speeds. W. Froude did not give these extrapolated figures in his reports, but suggested two methods which might be used for their derivation. In his own words, "it is at once seen that, at a length of 50 feet, the decrease, with increasing length, of the friction per square foot of every additional length is so small that it will make no very great difference in our estimate of the total resistance of a surface 300 ft long whether we assume such decrease to continue at the same rate throughout the last 250 feet of the surface, or to cease entirely after 50 feet; while it is perfectly certain that the truth must lie somewhere between these assumptions." Payne, (1936) has reproduced the curve Froude used at Torquay in 1876 for ships up to 152.4 m (500 ft) in length. This curve is almost an arithmetic mean between those which would be obtained by the two methods suggested. W. Froude (1874) also obtained some full-scale information in an attempt to confirm his law of comparison and to assist in the extrapolation of the frictional coefficients to ship lengths by carrying out towing tests on the sloop HMS *Greyhound,* a wooden ship 52.58 m (172 ft 6 in.) in length, with copper sheathing over the bottom. The results of the towing tests and the predictions made from the model are given in Table 2.

**Table 2** Results of Towing Trials on HMS *Greyhound*

The actual ship resistance was everywhere higher than that predicted from the model, the percentage increase becoming less with increasing speed. The difference in $R/V^2$, however, is almost the same at all speeds, except the lowest, and decreases only slowly with increasing speed, as might occur if this additional resistance were of viscous type and varying at some power less than the second. Froude pointed out that the additional resistance could be accounted for by assuming that the copper-sheathed hull was equivalent to smooth varnish over 2/3 of the wetted surface and to calico over the rest. This he considered reasonable, and the two resistance curves were then almost identical, which he took as a visible demonstration of the correctness of his law of comparison.

In his paper on the *Greyhound* trials, Froude states quite clearly how he applied his idea of the "equivalent plank" resistance: "For this calculation the immersed skin was carefully measured, and the resistance due to it determined upon the hypothesis that it is equivalent to that of a rectangular surface of equal area, and of length (in the line of motion) equal to that of the model, moving at the same speed."

The 1876 values of frictional coefficients were stated to apply to new, clean, freshly painted steel surfaces, but they lie considerably above those now generally accepted for smooth surfaces. The original curves have

**<u>Questão 14</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the critical velocity of the fluid over a given length of pipe when plotted logarithmically varies**:

(a) Inversely with kinematic viscosity and directly with diameter of the pipe.

(b) Directly with kinematic viscosity and inversely with diameter of the pipe.

(c) Inversely with kinematic viscosity and diameter of the pipe.

(d) Directly with kinematic viscosity and diameter of the pipe.

(e) Inversely with kinematic viscosity and directly with the length of the pipe.

**Questão 14 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 3. **Página 9.**

The resistance experienced by the fluid over a given length of pipe was measured by finding the loss of pressure head. Various diameters of the tube, $D$, were used, and the kinematic viscosity was varied by heating the water. Reynolds found that the laws of resistance exactly corresponded for velocities in the ratio $v/D$, and when the results were plotted logarithmically

$$V_c = 2000v/D$$

Below the critical velocity the resistance to flow in the pipe varied directly as the speed, while for higher velocities it varied at a power of the speed somewhat less than 2.

When the foregoing relationship is written in the form

$$V_cD/v = 2000$$

**<u>Questão 15</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), Reynolds found in his experiments in a dye pipe that:**

(a) Below the critical velocity the resistance to flow in the pipe varied directly as the speed, while for higher velocities it varied at a power of the speed somewhat smaller than 2.

(b) Below the critical velocity the resistance to flow in the pipe varied directly as the speed, while for higher velocities it varied at a power of the speed equal to 2.

(c) Below the critical velocity the resistance to flow in the pipe varied directly as the speed, while for higher velocities it varied at a power of the speed somewhat higher than 2.

(d) Below the critical velocity the resistance to flow in the pipe varied at a power of the speed somewhat smaller than 2, while for higher velocities it varied at a power of the speed somewhat higher than 2.

(e) Below the critical velocity the resistance to flow in the pipe varied at a power of the speed equal to 2, while for higher velocities it varied at a power of the speed somewhat higher than 2.

**Questão 15 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 3. **Página 9.**

The resistance experienced by the fluid over a given length of pipe was measured by finding the loss of pressure head. Various diameters of the tube, $D$, were used, and the kinematic viscosity was varied by heating the water. Reynolds found that the laws of resistance exactly corresponded for velocities in the ratio $v/D$, and when the results were plotted logarithmically

$$V_c = 2000v/D$$

Below the critical velocity the resistance to flow in the pipe varied directly as the speed, while for higher velocities it varied at a power of the speed somewhat less than 2.

When the foregoing relationship is written in the form

$$V_cD/v = 2000$$

**Questão 16** – **According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding laminar and turbulent flow, analyze the affirmatives below and choose the CORRECT answer:**

**I – At low values of VD/$\nu$, when the dye filament retained its own identity, the fluid was evidently flowing in layers which did not mix transversely but slid over one another at relative constant speed across the pipe section.**

**II – Laminar flow is associated with a relatively low resistance.**

**III – When the Reynolds number VD/$\nu$ increased, either by increasing VD or by decreasing $\nu$, the laminar flow broke down, the fluid mixed transversely in eddying motion.**

**IV – Turbulent flow is associated with increased resistance.**

(a) All are true.

(b) Only I, II and III are true.

(c) Only II, III and IV are true.

(d) Only II and IV are true.

(e) Only I and III are true.

**Questão 16 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 3. **Página 9.**

Experiments such as those performed by Reynolds suggested that there were two separate flow regimes possible, each associated with a different resistance law. At low values of *VD/v*, when the dye filament retained its own identity, the fluid was evidently flowing in layers which did not mix transversely but slid over one another at relative speeds which varied across the pipe section. Such flow was called laminar and was associated with a relatively low resistance. When the Reynolds number *VD/v* increased, either by increasing *VD* or by decreasing v, the laminar flow broke down, the fluid mixed transversely in eddying motion, and the resistance increased. This flow is called turbulent.

**Questão 17** – **De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:**

**I – O fluxo laminar se torna instável com o número de Reynolds na ordem de $4{,}5 \times 10^5$.**

**II – Com o fluxo sendo laminar, a resistência varia com $V^{1,5}$ e com o fluxo turbulento, a resistência varia com $V^{1,8}$.**

**III – Na transição do fluxo laminar para turbulento, o valor de $C_F$ irá diminuir ao longo da linha de transição, e finalmente aproximar-se da linha turbulenta assintoticamente.**

**IV – As linhas de transição para "*smooth planks*" ocorrem a valores de número de Reynolds dentro de uma faixa que a maioria dos testes de fricção com placas foram realizados, e se tais resultados forem usados para prever os valores de $C_F$ a número de Reynolds apropriado para um navio, 100 vezes ou mais do que os maiores valores para placas, somente os resultados para fluxos totalmente turbulentos podem ser apropriadamente usados.**

(a) Todas são verdadeiras.

(b) Apenas I e II são verdadeiras.

(c) Apenas I, II e IV são verdadeiras.

(d) Apenas I, III e IV são verdadeiras.

(e) Apenas III e IV são verdadeiras.

**Questão 17 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 3. **Página 10.**

**Página 10.**

This line is plotted in Fig. 2. Blasius found good agreement between his calculated resistances and direct experiment, but found that the laminar flow became unstable at Reynolds numbers of the order of 4.5 x $10^6$, beyond which the resistance coefficients increased rapidly above those calculated from his equation.

Prandtl and von Karman (1921) separately published the equation

$$C_F = \frac{R_F}{\frac{1}{2}\rho S V^2} = 0.072(VL/\nu)^{-1/5} \quad (16)$$

for turbulent flow, which is also shown in Fig. 2. This equation was based on an analytical and experimental investigation of the characteristics of the boundary layer, as well as on the available measurements of overall plank resistance, principally those of Froude and further experiments run by Gebers in the Vienna tank (Gebers, 1919).

At low values of Reynolds number, and with quiet water, the resistance of a smooth plank closely follows the Blasius line, the flow being laminar, and from Equation (15) it is seen that the resistance $R$ varies as $V^{1.8}$.

For turbulent flow, the value of the resistance coefficient is considerably higher than for laminar flow, and varies as a higher power of the speed; according to Equation (16) as $V^{1.8}$.

**Página 10.**

The transition from laminar flow to turbulent flow does not occur simultaneously over the whole plank. Transition begins when the Reynolds number reaches a critical value $R_c$. As the velocity $V$ increases beyond this value, the transition point moves forward so that the local value of the Reynolds number, $Vx/\nu$, remains equal to the critical value, $x$ being the distance of the transition point from the leading edge of the plank. This is called the "local Reynolds number," and for the constant value of this local Rn at which transition takes place, $x$ will decrease as $V$ increases, and more and more of the plank surface will be in turbulent flow and so experience a higher resistance. The value of $C_F$ will thus increase along a transition line of the type shown in Fig. 2, and finally approach the turbulent line asymptotically. It should be noted that there is no unique transition line, the actual one followed in a given case depending upon the initial state of turbulence in the fluid, the character of the plank surface, the shape of the leading edge, and the aspect ratio.

...

which most plank-friction tests have been run, and if such plank results are to be used to predict the values of $C_F$ at Reynolds numbers appropriate to a ship—100 times or so larger than the highest plank values—only those results for fully turbulent flow can properly be used.

**<u>Questão 18</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), não existe uma linha única de transição do fluxo laminar para o turbulento, assim sendo, a linha que deverá ser seguida depende dos seguintes fatores, EXCETO:**

(a) Estado inicial de turbulência do fluido

(b) Característica da superfície da placa

(c) Formato do bordo de ataque

(d) Velocidade da placa

(e) Razão de aspecto (AR)

**Questão 18 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 3. **Página 10.**

This is called the "local Reynolds number," and for the constant value of this local Rn at which transition takes place, $x$ will decrease as $V$ increases, and more and more of the plank surface will be in turbulent flow and so experience a higher resistance. The value of $C_F$ will thus increase along a transition line of the type shown in Fig. 2, and finally approach the turbulent line asymptotically. It should be noted that there is no unique transition line, the actual one followed in a given case depending upon the initial state of turbulence in the fluid, the character of the plank surface, the shape of the leading edge, and the aspect ratio.

**<u>Questão 19</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), a "*model–ship correlation line*" ou ITTC de 1957 é igual a curva proposta por Hughes mais um valor constante de:**

(a) 10%

(b) 12%

(c) 15%

(d) 20%

(e) 25%

**Questão 19 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 3. **Página 14.**

The Hughes proposal in Equation (19) is of the same general type as the ITTC line but gives much lower values of $C_F$ than either the ITTC 1957 formulation or the ATTC 1947 line. On the other hand, the Hughes line does claim to be a true friction line for smooth plates in fully turbulent, two-dimensional flow, but its low values have been criticized by many other workers in this field. The 1957 ITTC line, in fact, gives numerical values of $C_F$ which are almost the same as those of the Hughes line with a constant addition of 12 percent.

Granville (1977) showed that the 1957 ITTC model-ship correlation line can also be considered as a turbulent flat plate (two-dimensional) frictional resistance line. From fundamental considerations involving the velocity distribution in the boundary layer, he derived the general formula

**<u>Questão 20</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), Hughes propôs um novo método de extrapolação. Ele assumiu que o coeficiente de resistência total do modelo $C_{TM}$ seria composto por:**

(a) $C_{VM}$ e $C_{WM}$

(b) $C_{RM}$ e $C_{WM}$

(c) $C_{VM}$ e $C_{RM}$

(d) $C_{FM}$ e $C_{RM}$

(e) $C_{FM}$ e $C_{WM}$

**Questão 20 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 3. **Página 14.**

3.6 Three-Dimensional Viscous Resistance Formulations. In association with his two-dimensional line, Hughes proposed a new method of extrapolation from model to ship. He assumed that the total model resistance coefficient $C_{TM}$ could be divided into two parts, $C_{VM}$ and $C_{WM}$, representing the viscous and wavemak-ing resistance, respectively. At low Froude numbers, $C_{WM}$ will become very small, and at a point where wavemaking can be neglected, the curve of $C_{TM}$ will become approximately parallel to the two-dimensional friction line. Hughes called this point the *run-in* point. The value of $C_{TM}$ at this point can then be identified with the total viscous resistance coefficient $C_{VM}$ at the same point $Rn_0$.

**<u>Questão 21</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), o "*run-in point*" de um navio é o ponto onde:**

(a) A curva $C_{FO}$ do modelo coincide com a $C_{FO}$ do navio.

(b) A curva $C_{TM}$ se tornará igual a $C_{TS}$.

(c) A curva de resistência viscosa é totalmente composta por $C_{FO}$.

(d) A curva de $C_{TM}$ é a soma de $C_{FO}$ com $C_{WM}$.

(e) A curva de $C_{TM}$ é bem próxima da curva de $C_{VM}$.

**Questão 21 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 3. **Página 14.**

3.6 Three-Dimensional Viscous Resistance Formulations. In association with his two-dimensional line, Hughes proposed a new method of extrapolation from model to ship. He assumed that the total model resistance coefficient $C_{TM}$ could be divided into two parts, $C_{VM}$ and $C_{WM}$, representing the viscous and wavemak-ing resistance, respectively. At low Froude numbers, $C_{WM}$ will become very small, and at a point where wavemaking can be neglected, the curve of $C_{TM}$ will become approximately parallel to the two-dimensional friction line. Hughes called this point the *run-in* point. The value of $C_{TM}$ at this point can then be identified with the total viscous resistance coefficient $C_{VM}$ at the same point $Rn_0$.

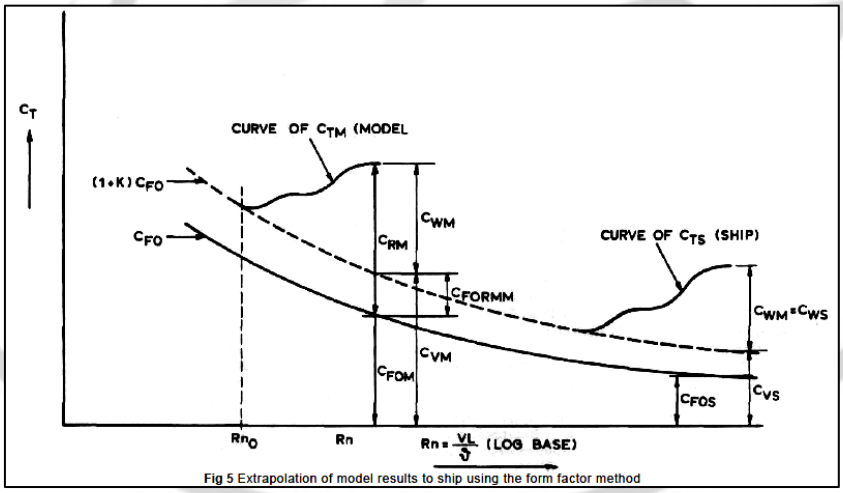


Fig 5 Extrapolation of model results to ship using the form factor method

**<u>Questão 22</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), o coeficiente de resistência de forma do modelo é definido como:**

(a) Razão entre coeficiente de resistência total do modelo e coeficiente de resistência friccional do modelo em qualquer ponto da curva de resistência.

(b) Razão entre coeficiente de resistência viscosa do modelo e coeficiente de resistência friccional do modelo em qualquer ponto da curva de resistência.

(c) Razão entre coeficiente de resistência de ondas do modelo e coeficiente de resistência viscosa do modelo, ambos no "*run-in point*".

(d) Razão entre coeficiente de resistência viscosa do modelo e coeficiente de resistência friccional do modelo, ambos no "*run-in point*".

(e) Razão entre coeficiente de resistência total do modelo e coeficiente de resistência friccional do modelo, ambos no "*run-in point*".

**Questão 22 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 3. **Página 14.**

The form resistance coefficient, due at least in part to the curvature of the hull (see Fig. 5), is defined by

$$1 + k = \frac{C_{TM}(\mathrm{Rn}_o)}{C_{FO}(\mathrm{Rn}_o)}$$

The three-dimensional model viscous resistance for arbitrary Rn can now be written as $C_{VM} = (1 + k)\ C_{F0}$ (Rn) where $C_{F0}$ is the equivalent flat-plate resistance coefficient. The factor $k$ accounts for the three-dimensional form, and is appropriately termed the form fac-

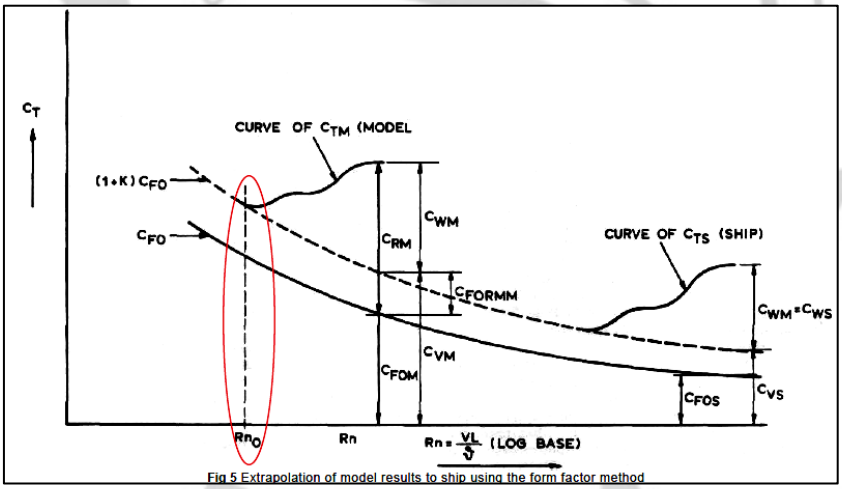


Fig 5 Extrapolation of model results to ship using the form factor method

**Questão 23** – **De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre os métodos de Froude e tridimensional, analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:**

**I – No método de Froude, todo o coeficiente de resistência residual do modelo é transferido para o navio sem ser alterado.**

**II – No método do fator de forma, somente a parte de $C_{RM}$ atribuído ao efeito viscoso é reduzido na transferência.**

**III – O método bidimensional fornece previsões substancialmente menores para os navios, exigindo assim maiores valores de correções. Esse procedimento evita valores negativos de correções encontrados quando o método tridimensional é utilizado.**

**IV – No método de Froude, somente a inclinação da linha de fricção bidimensional importa, enquanto no caso do fator de forma a linha a posição horizontal da linha também afetam a previsão do navio. A escolha da linha básica se torna um fator essencial no caso da aproximação tridimensional.**

(a) Todas são verdadeiras.

(b) Apenas I, II e III são verdadeiras.

(c) Apenas I, II e IV são verdadeiras.

(d) Apenas III e IV são verdadeiras.

(e) Apenas I e II são verdadeiras.

**Questão 23 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 3. **Página 15.**

tor. The form factor $(1 + k)$ is assumed to be invariant with Rn and the line $(1 + A;)C_{FO}$ is now taken as the extrapolator for the hull form concerned, and the ship curve of $C_{TS}$ can be drawn above the $(1 + k)C_{FO}$ curve at the appropriate values of the Reynolds number. In the Froude method the whole of the model residuary-resistance coefficient $C_R$ is transferred to the ship unchanged, while in the form factor method only that part of $C_R$ attributed to viscous effects ($C_{FORM}$ in Fig. 5) is reduced in the transfer. Accordingly, the three-dimensional method gives substantially lower ship predictions and so calls for larger values of the correlation allowance $C_A$. This procedure avoids the negative allowances sometimes found when using the Froude method. It should also be noted that in the case of the Froude method only the slope of the two-dimensional friction line matters while in the case of the form factor approach the vertical position of the line also affects the ship prediction. The choice of the basic line becomes an essential factor in the case of the three-dimensional approach.

**<u>Questão 24</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), para a resistência de ondas existir, é necessário que haja:**

(a) Viscosidade, apenas

(b) Superfície livre, apenas

(c) Viscosidade e superfície livre, apenas

(d) Vórtices e superfície livre, apenas

(e) Viscosidade, vórtices e superfície livre

**Questão 24 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 4. **Página 15.**

**4.1 General.** The wave-making resistance of a ship is the net fore-and-aft force upon the ship due to the fluid pressures acting normally on all parts of the hull, just as the frictional resistance is the result of the tangential fluid forces. In the case of a deeply submerged body, travelling horizontally at a steady speed far below the surface, no waves are formed, but the normal pressures will vary along the length. In a non-viscous fluid the net fore-and-aft force due to this variation would be zero, as previously noted.

If the body is travelling on or near the surface, however, this variation in pressure causes waves which alter the distribution of pressure over the hull, and the resultant net fore-and-aft force is the wave-making resistance. Over some parts of the hull the changes in pressure will increase the net sternward force, in others decrease it, but the overall effect must be a resistance of such magnitude that the energy expended in moving the body against it is equal to the energy necessary to maintain the wave system. The wave-making resistance depends in large measure on the shapes adopted for the area curve, waterlines and transverse sections, and its determination and the

**<u>Questão 25</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:**

**I – A resistência de ondas é uma cadeia de forças *fore-and-aft* no navio devido a pressões no fluido agindo normalmente em todas as partes do casco, assim como a resistência friccional é resultado das forças tangenciais do fluido.**

**II – No caso de um corpo perfeitamente submerso, viajando horizontalmente com velocidade constante, nenhuma onda será formada, mas as pressões normais variarão ao longo do seu comprimento. Num fluido não viscoso, a cadeia de forças *fore-and-aft* devido a essa variação será zero.**

**III – Se um corpo está navegando na superfície ou próximo dela, a variação de pressão provocará ondas que alteram a distribuição de pressões ao longo do casco, e a cadeia de forças resultantes *fore-and-aft* é a resistência de ondas.**

**IV – Em algumas partes do casco a mudança em pressão aumentará a força direcionada para ré e outras diminuirá, mas o efeito geral deve ser uma resistência de tal magnitude que a energia gasta para mover o corpo contra ela é igual a energia necessária para manter o sistema de ondas.**

(a) Todas são verdadeiras.

(b) Apenas I, II e III são verdadeiras.

(c) Apenas II, III e IV são verdadeiras.

(d) Apenas I e II são verdadeiras.

(e) Apenas III e IV são verdadeiras.

**Questão 25 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 4. **Página 15.**

**4.1 General.** The wave-making resistance of a ship is the net fore-and-aft force upon the ship due to the fluid pressures acting normally on all parts of the hull, just as the frictional resistance is the result of the tangential fluid forces. In the case of a deeply submerged body, travelling horizontally at a steady speed far below the surface, no waves are formed, but the normal pressures will vary along the length. In a non-viscous fluid the net fore-and-aft force due to this variation would be zero, as previously noted.

If the body is travelling on or near the surface, however, this variation in pressure causes waves which alter the distribution of pressure over the hull, and the resultant net fore-and-aft force is the wave-making resistance. Over some parts of the hull the changes in pressure will increase the net sternward force, in others decrease it, but the overall effect must be a resistance of such magnitude that the energy expended in moving the body against it is equal to the energy necessary to maintain the wave system. The wave-making resistance depends in large measure on the shapes adopted for the area curve, waterlines and transverse sections, and its determination and the

**<u>Questão 26</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the wavemaking resistance depends in large measure on:**

(a) Ship's speed, waterlines and transverse sections.

(b) Ship's speed, length and transverse sections.

(c) The shapes adopted for the area curve, length and transverse sections.

(d) The shapes adopted for the area curve, length and longitudinal sections.

(e) The shapes adopted for the area curve, waterlines and transverse sections.

**Questão 26 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 4. **Página 15.**

If the body is travelling on or near the surface, however, this variation in pressure causes waves which alter the distribution of pressure over the hull, and the resultant net fore-and-aft force is the wave-making resistance. Over some parts of the hull the changes in pressure will increase the net sternward force, in others decrease it, but the overall effect must be a resistance of such magnitude that the energy expended in moving the body against it is equal to the energy necessary to maintain the wave system. The wave-making resistance depends in large measure on the shapes adopted for the area curve, waterlines and transverse sections, and its determination and the

**<u>Questão 27</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding wave systems, analyze the affirmatives below and choose the WRONG answer:**

(a) This consists of a system of transverse waves following behind the point, together with a series of divergent waves radiating from the point.

(b) The whole pattern is contained within two straight lines starting from the pressure point and making angles of 19 deg 28 min on each side of the line of motion.

(c) The heights of successive transverse-wave crests along the middle line behind the pressure point increase going aft.

(d) The waves are curved back some distance out from the centerline and meet the diverging waves in cusps, which are the highest points in the system.

(e) The heights of the cusps decrease less rapidly with distance from the point than do those of the transverse waves, so that eventually well astern of the point the divergent waves become the more prominent.

**Questão 27 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 4. **Páginas 15 e 16.**

**Página 15.**

**4.2 Ship Wave Systems**. The earliest account of the way in which ship waves are formed is believed to be that due to Lord Kelvin (1887, 1904). He considered a single pressure point travelling in a straight line over the surface of the water, sending out waves which combine to form a characteristic pattern. This consists of a system of transverse waves following behind the point, together with a series of divergent waves radiating from the point, the whole pattern being contained within two straight lines starting from the pressure point and making angles of 19 deg 28 min

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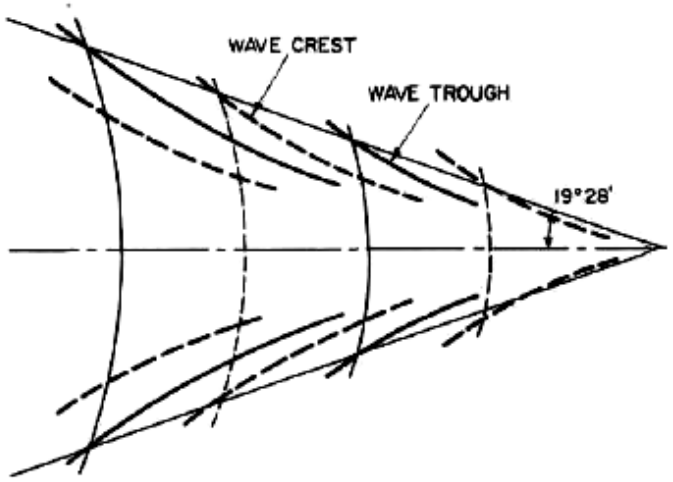



Fig 6 Kelvin wave pattern

on each side of the line of motion, Fig. 6. The heights of successive transverse-wave crests along the middle line behind the pressure point diminish going aft. The waves are curved back some distance out from the centerline and meet the diverging waves in cusps, which are the highest points in the system. The heights of these cusps decrease less rapidly with distance from the point than do those of the transverse waves, so that eventually well astern of the point the divergent

waves become the more prominent (see Fig. 7).

**Questão 28** – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre os sistemas de ondas transversais e divergentes, analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:

**I – As ondas divergentes mais notáveis na porção média do casco ou do modelo com *parallel body* ou logo atrás do navio em alta velocidade.**

**II – As ondas divergentes começam com uma grande *bow wave*, seguindo por outras de tal maneira que cada onda esteja uma atrás da outra em escala e tem um pequeno comprimento ao longo de sua linha da crista.**

**III – As ondas transversais são formadas entre as ondas divergentes em ambos os lados do navio, tendo suas cristas perpendiculares em relação à direção do movimento próximo ao casco e curvando para trás, conforme se aproximam das ondas divergentes, finalmente as encontrando.**

**IV – As ondas transversais são mais percebidas na proa do navio.**

(a) Todas são verdadeiras.

(b) Apenas I, II e III são verdadeiras.

(c) Apenas II e III são verdadeiras.

(d) Apenas I e IV são verdadeiras.

(e) Apenas II, III e IV são verdadeiras.

**Questão 28 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 4. **Página 16.**

The Kelvin wave pattern illustrates and explains many of the features of the ship-wave system. Near the bow of a ship the most noticeable waves are a series of divergent waves, starting with a large wave at the bow, followed by others arranged on each side along a diagonal line in such a way that each wave is stepped back behind the one in front in echelon (Fig. 8) and is of quite short length along its crest line. Between the divergent waves on each side of the ship, transverse waves are formed having their crest lines normal to the direction of motion near the hull, bending back as they approach the divergent-system waves and finally coalescing with them. These transverse waves are most easily seen along the middle portion of a ship or model with parallel body or just behind a ship running at high speed. It is easy to see the general Kelvin pattern in such a bow system.

Similar wave systems are formed at the shoulders, if any, and at the stern, with separate divergent and transverse patterns, but these are not always so clearly distinguishable because of the general disturbance already present from the bow system.

Since the wave pattern as a whole moves with the ship, the transverse waves are moving in the same direction as the ship at the same speed $V$, and might

**Questão 29** – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:

I – Os sistemas de ondas transversais e divergentes são formados nos "*shoulders*", se tiver, na proa e na popa, mas nem sempre são claramente distinguíveis por causa da perturbação provocado pelo sistema de onda de proa.

II – O sistema todo se move com o navio, tendo as ondas transversais a mesma direção e velocidade do navio e tem o comprimento apropriado para ondas livres na superfície naquela velocidade.

III – Na realidade, o comprimento de onda das ondas transversais nas imediações de um modelo é um pouco menor, mas o atinge cerca de dois comprimentos de onda a ré.

IV – A velocidade das ondas divergentes na direção perpendicular a sua crista é igual a velocidade do navio.

(a) Todas são verdadeiras.

(b) Apenas I, II e III são verdadeiras.

(c) Apenas I e II são verdadeiras.

(d) Apenas III e IV são verdadeiras.

(e) Apenas II, III e IV são verdadeiras.

**Questão 29 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 4. **Páginas 16 e 17.**

**Página 16.**

Similar wave systems are formed at the shoulders, if any, and at the stern, with separate divergent and transverse patterns, but these are not always so clearly distinguishable because of the general disturbance already present from the bow system.

Since the wave pattern as a whole moves with the ship, the transverse waves are moving in the same direction as the ship at the same speed $V$, and might

**Página 17.**

be expected to have the length appropriate to free waves running on surface at that speed

$$L_W = 2\pi V^2/g$$

Actually, the waves in the immediate vicinity of a model are found to be a little shorter, but they attain the length $L_w$ about two wave lengths astern.

The divergent waves will have a different speed along the line normal to their crests (Fig. 9). In this case, the component of speed parallel to the line of the ship's motion must be equal to the ship's speed in order to retain the fixed pattern relative to the ship. If the line normal to the crest of a divergent wave makes an angle $\theta$ with the ship's course, the speed in that direction will be $V\cos\theta$, and the corresponding wave length

$$L_w' = (2\pi V^2/g)\cos^2\theta$$

**<u>Questão 30</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding wave-making resistance for surface ships, analyze the affirmatives below and choose the WRONG answer:**

(a) At first, the value of CT decreases with increase of speed because of the waves are less important at low speeds and the resistance is almost wholly viscous in character.

(b) With further increase in speed, the value of CT begins to increase more and more rapidly, and at Froude numbers approaching 0.45 the resistance may vary at a power of V of 6 or more.

(c) The general increase in CT is usually accompanied by a number of humps and hollows in the resistance curve.

(d) As the speed of the ship increases, the wave pattern must change, for the length of the waves will increase and the relative positions of their crests and troughs will alter. In this process there will be a succession of speeds when the crests of the two systems reinforce one another, separated by other speeds at which crests and troughs tend to cancel one another.

(e) The energy of the systems depends upon the square of the wave breadth, this means alternating speeds of higher and lower than average resistance.

**Questão 30 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 4. **Páginas 17 e 19.**

**Página 17.**

$$L'_w = (2\pi V^2/g)\cos^2\theta$$

**4.3 Wave-Making Resistance of Surface Ships.** At low speeds, the waves made by the ship are very small, and the resistance is almost wholly viscous in character. Since the frictional resistance varies at a power of the speed a little less than the square, when the coefficient of total resistance $C_T = R_T/\frac{1}{2}\rho SV^2$ is plotted to a base of Froude number Fn (or of $V_K/\sqrt{L}$), at first the value of $C_T$ decreases with increase of speed (Fig. 10). With further increase in speed, the value of $C_T$ begins to increase more and more rapidly, and at Froude numbers approaching 0.45 ($V_K/\sqrt{L} = 1.5$) the resistance may vary at a power of $V$ of 6 or more. However, this general increase in $C_T$ is usually accompanied by a number of humps and hollows in the resistance curve. As the speed of the ship increases, the wave pattern must change, for the length of the waves will increase and the relative positions of their crests and troughs will alter. In this process there will be a succession of speeds when the crests of the two systems reinforce one another, separated by other speeds at which crests and troughs tend to cancel one another. The former condition leads to higher wave heights, the latter to lower ones, and as the energy of the systems

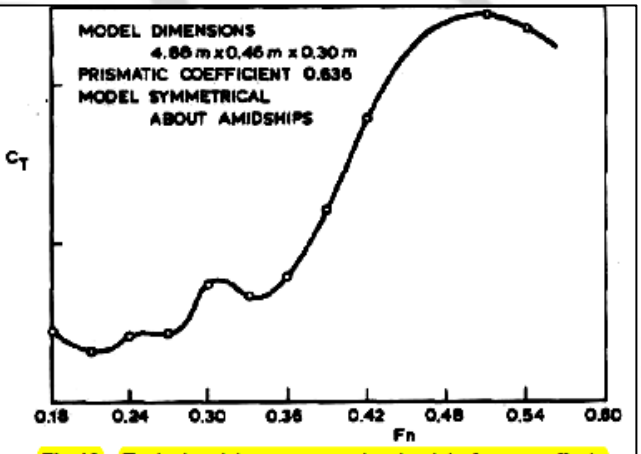



Fig 10 Typical resistance curve, showing interference effects

**Página 19.**

depends upon the square of the wave heights, this means alternating speeds of higher and lower than average resistance. The humps and hollows in the $C_T$ curve are due to these interference effects between the wave systems, and it is obviously good design practice to ensure whenever possible that the ship will be running under service conditions at a *favorable speed*. As will be seen later, it is the dependence of these humps and hollows on the Froude number that accounts for the close relationship between economic speeds and ship lengths.

**<u>Questão 31</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), a fim de experimentar somente a resistência de ondas (*wave-making resistance*), qual(is) a(s) propriedade(s) do fluido considerada(s) nos experimentos de Michell e Havelock:**

(a) Apenas a incompressibilidade

(b) Apenas a não viscosidade

(c) Apenas a incompressibilidade e não viscosidade

(d) Apenas a continuidade e incompressibilidade

(e) A incompressibilidade, continuidade e não viscosidade

**Questão 31 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 4. **Página 19.**

**4.4 Theoretical Calculation of Wave-Making Resistance.** Much research has been devoted to theoretical methods of calculating wave-making resistance and to their experimental verification (Lunde, 1957).

One method is to determine the flow around the hull and hence the normal pressure distribution, and then to integrate the fore-and-aft components of these pressures over the hull surface. This method was developed by Michell (1898) for a slender hull moving over the surface of a nonviscous fluid. It corresponds to the experimental technique employed by Eggert. The pioneer work of Michell was unfortunately overlooked and neglected for many years until rescued from obscurity by Havelock (1951).

A second method is to calculate the wave pattern generated by the ship at a great distance astern, as done by Havelock, the wave-making resistance then being measured by the flow of energy necessary to maintain the wave system. This method has been used experimentally by Gadd, et al (1962), Eggers (1962), Ward (1962) and many others.

Both methods lead to the same final mathematical expression, and in each case the solution is for a nonviscous and incompressible fluid, so that the ship will experience only wave-making resistance (Timman, et al, 1955).

**<u>Questão 32</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding the method developed by Michell for calculating wave-making resistance, analyze the affirmatives below and choose the WRONG answer:**

(a) This method is to determine the flow around the hull and hence the normal pressure distribution, and then to integrate the fore-and-aft components of these pressures over the hull surface.

(b) This method is for a slender hull moving over the surface of a non-viscous fluid.

(c) The hull is narrow compared with its length, so that the slope of the surface relative to the centerline plane is large.

(d) The waves generated by the ship have heights small compared with their lengths, so that the squares of the particle velocities can be neglected compared with the ship speed.

(e) The ship does not experience any sinkage or trim.

**Questão 32 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 4. **Página 19.**

**4.4 Theoretical Calculation of Wave-Making Resistance.** Much research has been devoted to theoretical methods of calculating wave-making resistance and to their experimental verification (Lunde, 1957).

One method is to determine the flow around the hull and hence the normal pressure distribution, and then to integrate the fore-and-aft components of these pressures over the hull surface. This method was developed by Michell (1898) for a slender hull moving over the surface of a nonviscous fluid. It corresponds to the experimental technique employed by Eggert. The pioneer work of Michell was unfortunately overlooked and neglected for many years until rescued from obscurity by Havelock (1951).

The theory as developed by Michell is valid only for certain restrictive conditions:

*(a)* The fluid is assumed to be nonviscous and the flow irrotational. Under these circumstances the motion can be specified by a velocity potential $\phi_s$, which in addition must satisfy the necessary boundary conditions.

*(b)* The hull is narrow compared with its length, so that the slope of the surface relative to the centerline plane is small.

*(c)* The waves generated by the ship have heights small compared with their lengths, so that the squares of the particle velocities can be neglected compared with the ship speed.

*(d)* The ship does not experience any sinkage or trim.

The boundary conditions to be satisfied by the velocity potential $\phi$ are:

*(a)* At all points on the surface of the hull, the normal velocity relative to the hull must be zero.

*(b)* The pressure everywhere on the free surface of the water must be constant and equal to the atmospheric pressure.

**<u>Questão 33</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding the method developed by Havelock for calculating wave-making resistance, analyze the affirmatives below and choose the WRONG answer:**

(a) This method is to calculate the wave pattern generated by the ship at a great distance astern.

(b) In this method the wave-making resistance is measured by the flow of energy necessary to maintain the wave system.

(c) The restriction to a "thin" ship cannot be removed even if the sources and sinks are distributed over the hull surface itself.

(d) If the strengths of the sources and sinks are assumed to be everywhere proportional to the slope of the hull surface, this will result in a total strength of zero, and the total velocity potential will be the sum of those due to the individual sources and sinks and the uniform flow.

(e) Each source and sink when in motion in a fluid, on or near the surface, gives rise to a wave system, and by summing these up the total system for the ship can be obtained.

**Questão 33 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 4. **Páginas 19 e 20.**

**Página 19.**

A second method is to calculate the wave pattern generated by the ship at a great distance astern, as done by Havelock, the wave-making resistance then being measured by the flow of energy necessary to maintain the wave system. This method has been used experimentally by Gadd, et al (1962), Eggers (1962), Ward (1962) and many others.

The alternative method developed by Havelock, in which the wave-making resistance is measured by the energy in the wave system, makes use of the idea of sources and sinks.[12] This is a powerful tool with which to simulate the flow around different body shapes and so to find the wave pattern, pressure distribution, and resistance. A "thin" ship, for example, can be simulated by a distribution of sources on the centerline plane of the forebody and of sinks in the afterbody, the sum of their total strength being zero. The re-

**Página 20.**

striction to a "thin" ship can be removed if the sources and sinks are distributed over the hull surface itself. If the strengths of the sources and sinks are assumed

to be everywhere proportional to the slope of the hull surface, this will result in a total strength of zero, and the total velocity potential will be the sum of those due to the individual sources and sinks and the uniform flow.

Each source and sink when in motion in a fluid, on or near the surface, gives rise to a wave system, and by summing these up the total system for the ship can be obtained. Havelock by this method found the wave pattern far astern, and from considerations of energy obtained the wave-making resistance.

**Questão 34** – **De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre os estudos teóricos e práticos sobre a resistência de ondas, analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:**

**I – Após vários testes nas posições dos *sources and sinks* foi encontrado que, para navios a Fn de 0.1 a 0.35 a distribuição de *sources* ao longo de todo o comprimento se torna importante.**

**II – Para Fn mais altos, a geometria das extremidades são mais importantes.**

**III – A escolha de uma distribuição de singularidades que dará uma boa qualidade de resistência, obtendo uma geometria do casco correspondente e modificando o casco para obter um formato de navio a meia nau, obteve formas que diminuíram consideravelmente a resistência de ondas, normalmente associado com bulbo na proa e às vezes na popa também.**

**IV – Um navio SWATH é um exemplo de redução drástica da resistência de ondas pela utilização de formas de casco adequadas.**

(a) Todas são verdadeiras.

(b) Apenas I e II são verdadeiras.

(c) Apenas II e III são verdadeiras.

(d) Apenas III e IV são verdadeiras.

(e) Apenas I, II e III são verdadeiras.

**Questão 34 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 4. **Páginas 20 e 21.**

**Página 20.**

Professor Inui tried various distributions of sources and sinks (singularities) by volume over the curved surface, in a horizontal plane and over the vertical middle-line plane. For displacement ships at Froude numbers from 0.1 to 0.35, he found the geometry of the ends to be most important, and these could be represented quite accurately by singularities on the middle-line plane. For higher Froude numbers, the dis-

**Página 21.**

tribution of sources along the whole length becomes important. In summary, the method is to choose a singularity distribution which will give good resistance qualities, obtain the corresponding hull geometry, carry out resistance and wave-observation tests and modify the hull to give a more ship-shape form amidships. In this way Inui has been able to obtain forms with considerably reduced wave-making resistance, usually associated with a bulb at the stem and sometimes at the stern also.

To a certain degree, the hull forms of relatively high-speed merchant ships have improved because of the application of wave resistance theory. Pien et al (1972) proposed a hull-form design procedure for high-speed displacement ships aided by wave resistance theory. Inui and co-workers have applied the streamline tracing method to practical hull forms with flat bottoms and a design method for high-speed ships with the aid of minimum wave resistance theory has been proposed by Maruo et al (1977). The development of special types of hull forms for drastically reduced wave making have also been guided to a certain extent by wave resistance theory. One of these is the small waterplane area twin-hull (SWATH) ship, discussed in Section 9. The accuracy and usefulness of wave resistance theory was recently demonstrated at a workshop organized by the DTRC (Bai, et al, 1979).

**Questão 35** – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the results of mathematical research have been most valuable in providing an insight into the effects of mutual wave interference upon wave-making resistance. A most interesting example is that of a double-wedge-shaped body with parallel inserted in the middle, investigated by Wigley. Regarding the work conducted by Wigley, analyze the affirmatives below and choose the CORRECT answer:

I – The measured and calculated wave profile along the hull contains four terms.

II – Considerably aft of the form, all four systems become sine curves of continuously diminishing amplitude, of a length appropriate to a free wave travelling at the speed of the model, this length being reached after about two ship lengths.

III – The calculated profile along the model is the sum of these five systems, and the measured profile was in general agreement with it so far as shape and positions of the crests and troughs were concerned, but the heights of the actual waves towards the stern were considerably less than those calculated.

IV – As speed increases, the wave lengths of each of the four systems increase. Since the primary crests and troughs are fixed in position, the total wave profile will continuously change in shape with speed as the crests and troughs of the different systems pass through one another.

V – Two principal types of interference are between two systems of the same sign, e.g., bow and stern, or the shoulder systems, and between systems of opposite sign, e.g., bow and forward shoulder. The second type is the most important in this particular case, because the primary hollow of the first shoulder system can coincide with the first trough of the bow system before the latter has been materially reduced by viscous effects.

(a) All are true.

(b) Only I, II, III and V are true.

(c) Only I, II and Vare true.

(d) Only II, III and IV are true.

(e) Only III, IV and V are true.

**Questão 35 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 4. **Páginas 22 e 23.**

**Página 22.**

**4.5 Interference Effects**. The results of mathematical research have been most valuable in providing an insight into the effects of mutual wave interference upon wave-making resistance. A most interesting example is that of a double-wedge-shaped body with parallel inserted in the middle, investigated by Wigley (1931). The form of the hull and the calculated and measured wave profiles are shown in Fig. 15. He showed that the expression for the wave profile along the hull contained five terms:

*(a)* A symmetrical disturbance of the surface, which has a peak at bow and stern and a trough along the center, dying out quickly ahead and astern of the hull. It travels with the hull and because of its symmetry does not absorb any energy at constant speed, and four wave systems, generated at

**Página 23.**

*(c)* the forward shoulder, starting with a trough;
*(d)* the after shoulder also starting with a trough;
*(e)* the stern, beginning with a crest.

These five systems are shown in Fig. 15. Considerably aft of the form, all four systems become sine curves of continuously diminishing amplitude, of a length appropriate to a free wave travelling at the speed of the model, this length being reached after about two waves.

The calculated profile along the model is the sum of these five systems, and the measured profile was in general agreement with it so far as shape and positions of the crests and troughs were concerned, but the heights of the actual waves towards the stern were considerably less than those calculated (Fig. 15).

This simple wedge-shaped body illustrates clearly the mechanism of wave interference and its effects upon wave-making resistance. Because of the definite sharp corners at bow, stern, and shoulders, the four free-wave systems have their origins fixed at points along the hull. As speed increases, the wave lengths of each of the four systems increase. Since the primary crests and troughs are fixed in position, the total wave profile will continuously change in shape with speed as the crests and troughs of the different systems pass through one another. At those speeds where the interference is such that high waves result, the wave-making resistance will be high, and vice-versa.

**Página 23.**

In this simple wedge-shaped form the two principal types of interference are between two systems of the same sign, e.g., bow and stern, or the shoulder systems, and between systems of opposite sign, e.g., bow and forward shoulder. The second type is the most important in this particular case, because the primary hollow of the first shoulder system can coincide with the first trough of the bow system before the latter has been materially reduced by viscous effects.

Wigley calculated the values of $V/\sqrt{gL}$ for minima and maxima of the wave-making resistance coefficient $C_w$ for this form, and found them to occur at the following points:

| | Values of Fn | | | |
|---|---|---|---|---|
| Minima $C_w$ | — | 0.187 | — | 0.231 | — | 0.345 | — |
| Maxima $C_w$ | 0.173 | — | 0.205 | — | 0.269 | — | 0.476 |

The mathematical expression for the wave-making resistance $R_w$ is of the form

$R_w \propto V^6$ (constant term + 4 oscillating terms) so that the wave-making resistance coefficient $C_w$ is

$C_w = R_w/\frac{1}{2}\rho SV^2 = V^4$ (constant term + 4 oscillating terms) (23)

**<u>Questão 36</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), assinale a alternativa INCORRETA:**

(a) Em altas velocidades, os termos oscilatórios se cancelam e há um aumento constante em Cw, não existindo mais nenhum *hump* além daquele que ocorre a Fn = 0,45, depois do qual o valor de Rw diminui continuamente com o aumento da velocidade.

(b) Até Fn = 0,4, as ondas transversais são as principais responsáveis pela posição das cristas e cavados na curva de resistência. Acima dessa velocidade, a contribuição das ondas divergentes se torna cada vez mais importantes e a interferência apenas de ondas transversais não determinará corretamente a posição dos maiores *humps*, particularmente o último a Fn = 0,5.

(c) Conforme o navio avança, mas a água não, a proa fornece bastante energia à água que é empurrada lateralmente e para longe do navio. Esse espalhamento de energia resulta no aumento das alturas das ondas dos sistemas que se seguem, porém sem apreciável mudança no seu comprimento.

(d) Como a WMR é gerada principalmente pelas partes do casco próximo à superfície, é interessante que o deslocamento (W) do navio se mantenha o mais baixo possível.

(e) O relativo pequeno efeito da parte inferior do casco no sistema de ondas também significa que a WMR não é excessivamente sensível a seção de meia-nau.

**Questão 36 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 4. **Página 24.**

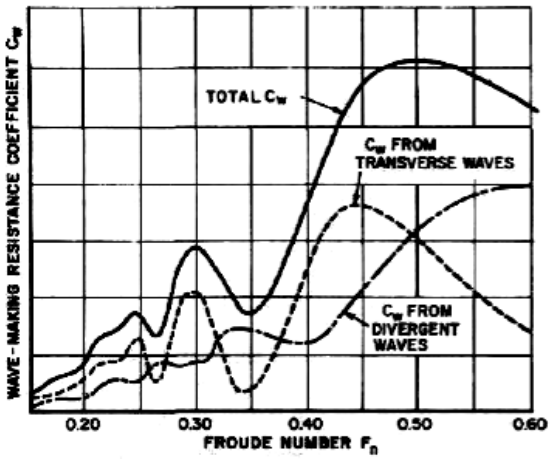



Fig 19 Contributions made by transvers e and divergent wave systems to wave resistance

The $C_W$ curve is thus made up of a steady increase varying as $V^4$ due to the constant term and four oscillating curves due to the interference between the different free-wave systems (Fig. 17). These latter ultimately, at very high speeds, cancel both each other and the steady increase in $C_W$, and there is no further hump beyond that occurring at a $V\sqrt{gL}$ value of about 0.45 after which the value of $R_W$ continuously decreases with further increase in speed. However, at these high speeds the hull will sink bodily and change trim so much that entirely new phenomena arise.

For more ship-shaped forms, where the waterlines are curved and have no sharp discontinuities, the wave pattern still consists of five components—a symmetrical disturbance and four free-wave systems (Wigley, 1934). Two systems begin with crests, one at the bow and one at the stern, and are due to the change in the angle of the flow at these points. The other two systems, like the shoulder systems in the straight line form, begin with hollows, but are no longer tied to definite points, since the change of slope is now gradual and spread over the whole entrance and run. They commence at the bow and after shoulder, respectively, as shown in Fig. 18, much more gradually than in the case of the wedge-shaped form. The one due to entrance curvature, for example, may be looked upon as a progressive reduction of that due to the bow angle as the slope of the waterline gradually becomes less in going aft.

Wigley also made calculations to show the separate contributions to the wave-making resistance of the transverse and divergent systems (Wigley, 1942). Up to a Froude number of 0.4 the transverse waves are mainly responsible for the positions of the humps and hollows, Fig. 19. Above this speed the contribution from the divergent waves becomes more and more important, and the interference of the transverse waves alone will not correctly determine the position of the higher humps, particularly the last one at Fn = 0.5.

The existence of interference effects of this kind was known to naval architects long before such mathematical analysis was developed. The Froudes demonstrated them in a striking way by testing a number of models consisting of the same bow and stern separated by different lengths of parallel body (Froude, W., 1877 and Froude, R.E., 1881). W. Froude's sketch of the bow wave system is shown in Fig. 20. As the ship advances but the water does not, much of the energy given to the water by the bow is carried out laterally and away from the ship. This outward spreading of the energy results in a decrease in the height of each succeeding wave of each system with no appreciable change in wave length. Fig. 21 shows a series of tests made at the EMB, Washington, and the corresponding curve of model residuary resistance plotted against length of parallel body (Taylor, 1943). The tests were not extended to such a length of parallel body that the bow system ceased to affect that at the stern. It is clear, however, that its effect is decreasing and would eventually died out, as suggested by the dotted extension of the resistance curve.

Fig. 22 shows a series of curves for the same form at various speeds. In this chart the change of parallel middle-body length which results in successive humps on any one curve is very nearly equal to the wave length for the speed in question, as shown for speeds of 2.6 and 3.2 knots. This indicates that ship waves do have substantially the lengths of deep-sea waves of the same speed.

If all the curves in Fig. 22 are extended in the direction of greater parallel-body length until the bow system ceases to affect the stern system, as was done in Fig. 21, the mean residuary resistances for this form, shown by the dashed lines at the left of the chart, are found to increase approximately as the sixth power of the speed. They are, in fact, the actual resistances stripped of interference effects and represent the true residuary resistances of the two ends. This rate of variation with speed is the same as that given by theory for the basic wave-making resistance before taking into account the interference effects (Fig. 17).

The mathematical theory indicates that the wave resistance is generated largely by those parts of the hull near the surface, which is in agreement with the experimental results obtained by Eggert. This suggests that from the point of view of reducing wave-making resistance the displacement should be kept as low down as possible. The relatively small effect of the lower part of the hull on the wave systems also means that the wave-making resistance is not unduly sensitive to the midship section shape (Wigley, et al, 1948).

**4.6 Effects of Viscosity on Wave-Making Resistance.** Calculations of wave-making resistance have so far been unable to take into account the effects of viscosity, the role of which has been investigated by Havelock (1923), (1935) and Wigley (1938). One of these

**<u>Questão 37</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre os efeitos da viscosidade na resistência de ondas, assinale a alternativa INCORRETA:**

(a) O efeito da camada limite separa o casco do fluxo potencial, e esse é um dos efeitos da viscosidade na WMR.

(b) A influência direta da viscosidade no movimento das ondas é grande, mas o efeito indireto pode ser compensado por alguns ajustes na forma do navio.

(c) Como a parte de ré do corpo (*after body*) é virtualmente aumentada e a linha d'água reduzida em inclinação, então a WMR na parte de ré (*after body*) é reduzida.

(d) A diferença em resistência, quando se considera a viscosidade, é de cerca de 4%.

(e) O aumento virtual do casco devido a viscosidade varia de 2% a 8%.

**Questão 37 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 4. **Páginas 24 e 26.**

**Página 24.**

**4.6 Effects of Viscosity on Wave-Making Resistance.** Calculations of wave-making resistance have so far been unable to take into account the effects of viscosity, the role of which has been investigated by Havelock (1923), (1935) and Wigley (1938). One of these

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effects is to create a boundary layer close to the hull, which separates the latter from the potential-flow pattern with which the theory deals. This layer grows thicker from stem to stern, but outside of it the fluid behaves very much in accordance with the potential flow theory. Havelock (1926) stated that the direct influence of viscosity on the wave motion is comparatively small, and the "indirect effect might possibly be allowed for later by some adjustment of the effective form of the ship." He proposed to do this by assuming that the after body was virtually lengthened and the aft end waterlines thereby reduced in slope, so reducing the after-body wavemaking. Wigley (1962) followed up this suggestion by comparing calculated and measured wave-making resistance for 14 models of mathematical forms, and deriving empirical correction factors. He found that the remaining differences in resistance were usually within 4 percent, and that the virtual lengthening of the hull due to viscosity varied between 2 and 8 percent.

**<u>Questão 38</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), o efeito de escala em Cw devido a viscosidade faz com que:**

(a) A curva de Cw medida seja maior que a calculada, mas mostra menores oscilações.

(b) A curva de Cw medida seja maior que a calculada e também mostra maiores oscilações.

(c) A curva de Cw calculada seja maior que a medida, porém com oscilações idênticas.

(d) A curva de Cw calculada seja maior que a medida, mas mostra menores oscilações.

(e) A curva de Cw calculada seja maior que a medida e também mostra maiores oscilações.

**Questão 38 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 4. **Página 26.**

**4.7 Scale Effect on Wave-Making Resistance.** Wigley (1962) has investigated the scale effect on $C_w$ due to viscosity, pointing out that the calculated curves of $C_w$ are usually higher than those measured in experiments and also show greater oscillations. These differences he assigned to three major causes:

*(a)* Errors due to simplifications introduced to make the mathematical work possible.

*(b)* Errors due to neglect of the effects of viscosity on $R_w$.

*(c)* Errors due to the effects of wave motion on $R_w$.

Errors under *(a)* will decrease with increasing speed, since they depend on the assumption that the velocities due to the wave motion are small compared with the speed of the model, which is more nearly fulfilled at high speed.

**Questão 39** – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre as causas do efeito de escala na Rw, analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:

I – Erros devido às simplificações introduzidas para possibilitar os cálculos matemáticos diminuem com o aumento a velocidade.

II – Erros por ignorar os efeitos da viscosidade em Rw depende do Rn, e, portanto, do tamanho do modelo, diminuindo com o aumento do tamanho. Testes com modelos assimétricos param de ser importantes para Fn>0,45.

III – Erros devidos ao movimento da onda em Rf são negligenciados a baixas velocidades, mas com Fn>0,35, eles se tornam importantes, evidenciado pelo afundamento (*sinkage*) e trim que aumentam rapidamente acima dessa velocidade.

IV – A WMR medida é menor que a calculada para Fn<0,35 em modelos típicos num fluido perfeito. Essa diferença é parcialmente devido à viscosidade e Cw aumentará com a escala ao invés de ser constante como assumido pela extrapolação.

(a) Todas são verdadeiras.

(b) Apenas I, II e III são verdadeiras.

(c) Apenas II, III e IV são verdadeiras.

(d) Apenas I e II são verdadeiras.

(e) Apenas III e IV são verdadeiras.

**Questão 39 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 4. **Página 26.**

**4.7 Scale Effect on Wave-Making Resistance.** Wigley (1962) has investigated the scale effect on $C_w$ due to viscosity, pointing out that the calculated curves of $C_w$ are usually higher than those measured in experiments and also show greater oscillations. These differences he assigned to three major causes:

*(a)* Errors due to simplifications introduced to make the mathematical work possible.

*(b)* Errors due to neglect of the effects of viscosity on $R_w$.

*(c)* Errors due to the effects of wave motion on $R_r$.

Errors under *(a)* will decrease with increasing speed, since they depend on the assumption that the velocities due to the wave motion are small compared with the speed of the model, which is more nearly fulfilled at high speed.

Errors under *(b)* will depend on Reynolds number, and therefore on the size of the model, decreasing as size increases. From experiments on unsymmetrical models tested moving in both directions, these errors cease to be important for Fn greater than 0.45.

At low speeds errors under *(c)* are negligible, but become important when Fn exceeds 0.35, ($V_k/\sqrt{L} = 1.15$) as evidenced by the sinkage and trim, which increase very rapidly above this speed.

A practical conclusion from this work is the effect on the prediction of ship resistance from a model. In a typical model the actual wave resistance is less than that calculated in a perfect fluid for Froude numbers less than about 0.35. This difference is partly due to viscosity, the effect of which will decrease with increased size, and $C_w$ will increase with scale instead of being constant as assumed in extrapolation work. Wigley made estimates of the difference involved in calculating the resistance of a 121.9 m ship from that of a 4.88 m model at a Froude number of 0.245 and found that the resistance of the ship would be underestimated, using the usual calculations, by about 9 percent, the variation with speed being approximately as shown in Fig. 23. The effect disappears at low speeds and for values of Fn above 0.45

**<u>Questão 40</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), assinale a alternativa INCORRETA:**

(a) No último *hump* (Fn=0,5), o Cw calculado é maior que o medido, devido ao fato de negligenciar o afundamento e o trim.

(b) Em todos os casos, as cristas e cavados na curva medida ocorre a valores mais altos de Fn do que o fornecido pela teoria, variando em quantidade de 2% a 8%.

(c) O modelo se comporta como se fosse maior que seu comprimento efetivo, e isto é, sem dúvida, devido principalmente ao aumento virtual do comprimento causado pela camada limite.

(d) A baixas velocidades (Fn=0,1), a WMR varia com o quadrado da tangente do semi-ângulo de entrada, mas seu valor total em termos de Rt é muito pequena.

(e) A altas velocidades, com Fn>1,0, a WMR varia aproximadamente com o quadrado do deslocamento, ilustrando o fato de que a forma do navio é relativamente sem importância, sendo a principal consideração o deslocamento a um certo comprimento.

**Questão 40 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 4. **Página 27.**

The last hump in the $C_W$ curve occurs at a Froude number of about 0.5, and here the calculated value of $C_W$ is less than the measured $C_{R_I}$ again possibly due to the neglect of sinkage and trim.

In all cases the humps and hollows on the measured curves occur at higher values of Fn than those given by theory, by amounts varying from 2 to 8 percent. In other words, the model behaves as though it were longer than its actual length, and this is undoubtedly due mostly to the virtual lenghening of the form due to the viscous boundary layer. At very low speeds, Fn = 0.1, the wave-making resistance varies approximately as the square of the tangent of the half-angle of entrance, but its total value in terms of $R_T$ is very small. At high speeds, with Fn greater than 1.0, the wave-making resistance varies approximately as the square of the displacement, illustrating the well-known fact that at very high speeds shape is relatively unimportant, the chief consideration being the displacement carried on a given length.

**Questão 41** – **According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), analyze the affirmatives below and choose the CORRECT answer:**

**I – The turbulent frictional belt around a ship consists of eddies, so that all forms of frictional resistance are really due to eddy-making.**

**II – The term eddy resistance is usually applied to the resistance due to eddy formation or disturbed streamline flow caused by abrupt changes of form, appendages or other projections, including tangential skin friction.**

**III – The intercept CRM between the curves of CFOM for the plank and CTM for the total model resistance is the so-called residuary-resistance coefficient.**

**IV – In a typical case the CTM curve at the very low values of Rn is almost parallel to the CFOM curve but some distance below it.**

(a) All are true.

(b) Only I and III are true.

(c) Only II and IV are true.

(d) Only I, II and III are true.

(e) Only I, III and IV are true.

**Questão 41 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 5. **Página 27.**

**5.1 Eddy Resistance, Viscous Pressure Drag, Separation Resistance and Wave-breaking Resistance.** The turbulent frictional belt around a ship consists of eddies, so that all forms of frictional resistance are really due to eddy-making. However, the term is usually applied to the resistance due to eddy formation or disturbed streamline flow caused by abrupt changes of form, appendages or other projections, and excludes tangential skin friction.

When the total model resistance $R_{TM}$ is measured over a range of speeds and plotted as the coefficient $C_{TM} = R_{TM}/\frac{1}{2}\rho SV^2$ against log Rn, the curve will be of the general shape shown in Fig. 25. Also shown is a curve of the coefficient of frictional resistance $C_{FOM}$ for a smooth plank in fully turbulent flow. The intercept $C_{RM}$ between the curves of $C_{FOM}$ for the plank and $C_{TM}$ for the total model resistance is the so-called residuary-resistance coefficient.

In a typical case the $C_{TM}$ curve at the very low values of Rn is almost parallel to the $C_{FOM}$-curve but some distance above it. Since the primary component of the coefficient $C_{WM}$ varies as the fourth power of the speed, (Equation 23) the wave-making resistance at very low

**<u>Questão 42</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), ao analisar o coeficiente de esbelteza (L/D), podemos AFIRMAR que:**

(a) Quanto maior L/D, maior será o coeficiente de forma (CFORM) e a curva de CT estará mais acima da curva CFOM.

(b) Quanto maior L/D, maior será o coeficiente de forma (CFORM) e a curva de CT estará mais próxima da curva CFOM.

(c) Quanto menor L/D, maior será o coeficiente de forma (CFORM) e a curva de CT estará mais acima da curva CFOM.

(d) Quanto menor L/D, menor será o coeficiente de forma (CFORM) e a curva de CT estará mais próxima da curva CFOM.

(e) A relação L/D não altera o coeficiente de forma (CFORM) e a curva de CT estará mais acima da curva CFOM.

**Questão 42 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 5. **Páginas 27 e 28.**

**Página 27.**

On this assumption the intercept *FE* (= *BC)* must be due to some other cause. Models of submarines and airships run fully submerged where wave-making is absent have resistances higher than the $C_{FOM}$-values for the equivalent plank, and this increase has been called the form resistance or form drag. Moreover, the form-resistance coefficient for such shapes is higher the smaller the slenderness ratio (the length-diameter ratio, *L/D);* i.e., the "stumpier" the models. A similar

**Página 28.**

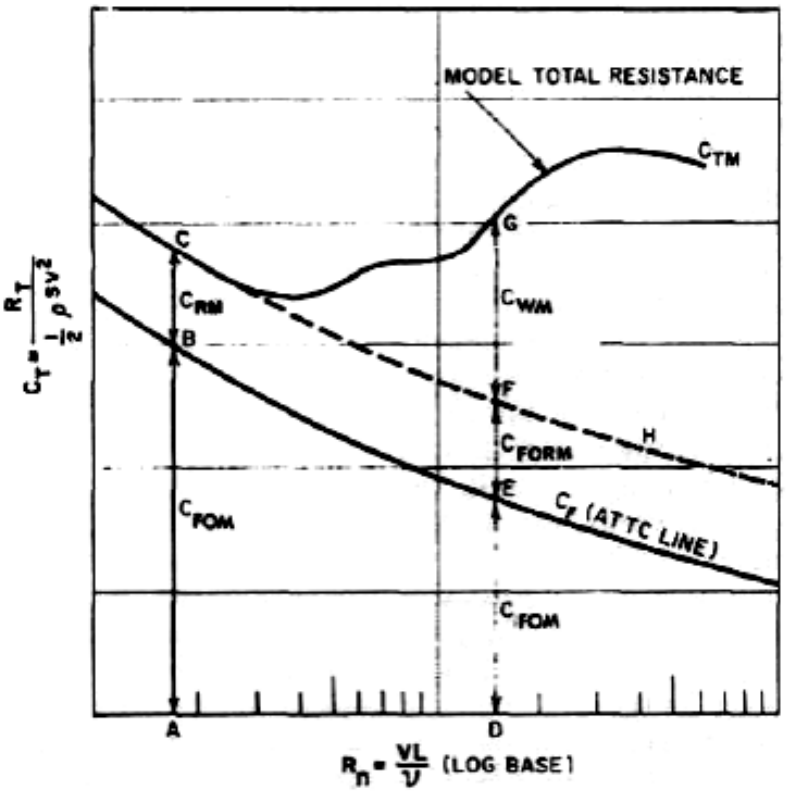



Fig 25 Elements of model resistance

effect is found in ship models, the intercept *BC* being greater the fuller the model and the smaller the ratio

**<u>Questão 43</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), assinale a alternativa INCORRETA:**

(a) O efeito da curvatura afeta a distribuição de pressões ao longo do comprimento, fazendo com que a velocidade aumente ao longo da porção média do casco e diminua na proa e popa.

(b) Navios de formas mais cheias experimentarão maior *skin friction* e, consequentemente, maior arrasto de forma.

(c) Se aumentarmos a relação L/D além de um certo ponto, a *form drag* e a resistência friccional aumentarão, pois terá uma maior área de superfície de contato com a água.

(d) Para navios de guerra CRM varia de 5% a 15% do CFOM.

(e) Para navios de carga, o CRM vai até 40% do CFOM ou mais.

**Questão 43 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 5. **Página 28.**

There are three main causes of this form resistance. The ordinate of the curve $C_{FOM}$ applies to a flat surface having the same length and wetted area as the model and so neglects any effects due to curvature of the hull. This curvature affects the pressure distribution along the length, causing the velocity to increase along most of the middle part and to decrease at the ends. The former effect outweighs the latter. Also, since the path along a streamline from bow to stern is longer on a shaped body than on a plank, the average velocity must be higher. Thus the real skin friction of a ship must be greater than that of the "equivalent plank." Since the pressure and velocity changes and the extra path length are greater the fuller and stumpier the form, such shapes would be expected to have greater form drag. This is borne out by experiments on bodies of revolution in air, where, for example, Young (1939) found form drag percentages varying with length-diameter ratio as follows:

| *L/D* | 10 | 5 | 3.33 |
|---|---|---|---|
| Form drag, percent ..... | 5 | 17 | 30 |

Similar figures have been found for bodies of revolution run deeply submerged in water. For a given volume of displacement, increases of *L/D* ratio beyond a certain point, while it may still reduce the form drag, will increase the frictional resistance because of the greater surface area and so in terms of total resistance there will be some optimum value of the *L/D* ratio. The value depends upon the exact shape and upon the amount of appendages necessary to give directional

stability, and varies between 5 and 7. For surface ships the intercept $C_{BM}$ has been found to vary from 5 to 15 percent of $C_{FOM}$ in warships and up to 40 percent or more in full cargo ships. These increases, however, cannot be attributed wholly to curvature effects, which leads to the other causes of form effect.

**Questão 44 – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), o valor ótimo de L/D depende do formato exato e da quantidade de apêndices necessários para dar estabilidade direcional. Esse valor varia entre:**

(a) 2 e 4

(b) 3 e 5

(c) 5 e 7

(d) 7 e 9

(e) 8 e 10

**Questão 44 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 5. **Página 28.**

Similar figures have been found for bodies of revolution run deeply submerged in water. For a given volume of displacement, increases of *L/D* ratio beyond a certain point, while it may still reduce the form drag, will increase the frictional resistance because of the greater surface area and so in terms of total resistance there will be some optimum value of the *L/D* ratio. The value depends upon the exact shape and upon the amount of appendages necessary to give directional

stability, and varies between 5 and 7. For surface ships the intercept $C_{BM}$ has been found to vary from 5 to 15 percent of $C_{FOM}$ in warships and up to 40 percent or
more in full cargo ships. These increases, however, cannot be attributed wholly to curvature effects, which leads to the other causes of form effect.

**<u>Questão 45</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), there are three main causes of the form resistance. They are:**

(a) Skin friction due to curvature of the hull, viscous pressure drag and separation resistance.

(b) Spray drag, viscous pressure drag and separation resistance.

(c) Eddy resistance, viscous pressure drag and separation resistance.

(d) Frictional resistance, eddy resistance and viscous pressure drag.

(e) Skin friction due to curvature of the hull, frictional resistance and eddy resistance.

**Questão 45 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 5. **Página 28.**

There are three main causes of this form resistance. The ordinate of the curve $C_{FOM}$ applies to a flat surface having the same length and wetted area as the model and so neglects any effects due to curvature of the hull. This curvature affects the pressure distribution along the length, causing the velocity to increase along most of the middle part and to decrease at the ends. The former effect outweighs the

In discussing wave-making resistance, it was pointed out that the existence of the boundary layer had the virtual effect of lengthening the form and reducing the slopes of the after waterlines. This is a region where the normal pressure on the hull is higher than the static pressure, owing to the closing in of the streamlines, and the forward components of these excess pressures will exert a forward thrust overcoming some of the ship's resistance. The presence of the boundary layer reduces these forward components, resulting in an increase in resistance as compared with that which would be experienced in a nonviscous fluid, and so is called the *viscous pressure drag*.

If the curvature near the stern becomes too abrupt, the bilge radius too hard, the after end sections too U-shaped or there are other discontinuities in the hull shape, the water may no longer be able to follow the hull and breaks away, and the intervening space between the hull and the smooth-flowing water is filled with eddies, as illustrated in Fig. 1*(d)*. A point at which this happens is called a separation point, and the resulting resistance is the third element of form drag, called separation resistance. Separation of this kind can also affect the pressure distribution on the hull, and so modify the viscous-pressure drag.

**Questão 46 – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the existence of the boundary layer has the virtual effect of lengthening the form and reducing the slopes of the after waterlines. This is a region where the normal pressure on the hull is higher than the static pressure, owing to the closing in of the streamlines, and the forward components of these excess pressures will exert a forward thrust overcoming some of the ship's resistance. The presence of the boundary layer reduces these forward components, resulting in an increase in resistance as compared with that which would be experienced in a non-viscous fluid, and so is called:**

(a) Eddy resistance

(b) Appendage resistance

(c) Skin drag

(d) Separation drag

(e) Viscous pressure drag

**Questão 46 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 5. **Página 28.**

> In discussing wave-making resistance, it was pointed out that the existence of the boundary layer had the virtual effect of lengthening the form and reducing the slopes of the after waterlines. This is a region where the normal pressure on the hull is higher than the static pressure, owing to the closing in of the streamlines, and the forward components of these excess pressures will exert a forward thrust overcoming some of the ship's resistance. The presence of the boundary layer reduces these forward components, resulting in an increase in resistance as compared with that which would be experienced in a nonviscous fluid, and so is called the *viscous pressure drag*.

**<u>Questão 47</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre a *wave breaking resistance*, assinale a alternativa INCORRETA:**

(a) A *wave breaking resistance* ocorre principalmente em cascos com formas mais cheias.

(b) Para Fn<0,1, a WMR dificilmente ocorre e a superfície livre na popa sobe a uma altura de aproximadamente $V^2/2g$, onde "V" é a velocidade do Navio, e "g" a aceleração da gravidade.

(c) A *wave breaking* contribui com uma parte muito pequena da resistência total de navios com formas cheias.

(d) A *bow wave breaking* pode ser considerada devido à separação do escoamento na superfície livre.

(e) A *bow wave breaking* pode ser evitada fazendo com que a tangente à curva das áreas das seções da perpendicular a vante não sejam muito íngremes.

**Questão 47 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 5. **Página 29.**

sible distortion. Fluid particles moving aft from midships, relative to the body, have their velocities diminished both by the shearing stresses and by the increasing pressures. Some of them may have insufficient kinetic energy to overcome the adverse pressure gradient and so come to rest before reaching the stern or even start to move forward. Following particles are then forced outward away from the body, setting up pressures which tend to move them back towards the hull, thus causing large scale vortices in the boundary layer. From this point the flow is separated from the hull and a widening band of eddying water intervenes between the hull and the smooth flow outside it. These eddies carry away the kinetic energy which has been expended in forming them and so give rise to separation drag. Sufficient is not yet known to divide the total viscous drag into its separate components, and this fact has an important bearing on the extrapolation of model results to the ship.

In addition to form and separation resistance, eddy-making resistance is also caused by struts, shafts, bossings and other appendages, as is discussed in Section 5.3.

Especially in the case of bluff hull forms the phenomenon of *wave-breaking* and wave-breaking resistance have to be considered as well. For this type of hull the flow ahead of the bow becomes irregular and complex, usually leading to a breaking wave.

At very low Froude numbers, below approximately 0.10, wave-making hardly occurs and the free surface at the stern rises to a height approximately equal to $V^2/2g$, where $V$ is the speed of the ship and $g$ the acceleration due to gravity, in accordance with the Bernoulli equation. As the ship speed increases however, this rise of the wave at the stern no longer occurs and instead the bow-wave breaks.

The resistance associated with wave-breaking at the stern has recently been the subject of extensive investigations. Important studies on this topic were made by Taneda, et al (1969), who presented the results of flow observations around a fishery training ship and its corresponding scaled model. Baba (1969) was the first to term the observed flow around the bow "wave-breaking" and presented measurements of momentum loss due to wave-breaking by means of a wake survey far behind a ship model. Baba proposed a hydraulic jump model as a means of calculating the momentum loss due to breaking waves. He showed that wave-breaking resistance may contribute an appreciable part of the total resistance of full forms. Dagan, et al (1969) carried out a theoretical study of the two-dimensional flow past a blunt body. The drag associated with wave-breaking was obtained by calculating the loss of momentum of the flow. Ogilvie (1973) obtained analytical results for the case of a fine wedge-shaped bow and obtained a universal curve for the shape of the bow wave on the hull. Experimental results generally confirm their predictions.

The most recent work in this area was carried out by Kayo et al (1981). They carried out systematic experiments on the effect of shear on the free surface. They concluded that bow wave-breaking can be considered to be due to flow separation at the free surface.

Bow wave-breaking can generally be avoided by requiring that the tangent to the curve of sectional areas at the forward perpendicular be not too steep. Taniguchi, et al (1966) derived a criterion for full form, low-speed ships that can be applied in this connection. The work carried out by Inui, et al (1979), Miyata, et al (1980) and Kayo, et al (1981) has resulted in a criterion based on the half-entrance angle of the waterline. Finally, the work carried out by Taylor, G.I. (1950) reveals that at a certain speed the free surface becomes unstable and breaks when the radius of curvature of the curved streamlines result in a value of the centrifugal acceleration $V^2/R$ greater than a critical value. This so-called Taylor instability criterion, when applied to the case of the flow around the stem of a ship with radius $R$, results in the approximate expression that $R \geq F^2/50$, with $R$ in meters and $V$ in m per sec, to avoid wave-breaking.

**5.2 Air and Wind Resistance**. A ship sailing on a smooth sea and in still air experiences a resistance due to the movement of the above-water hull through the

**Questão 48** – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre a resistência causada pelo vento, analise as afirmativas abaixo, identifique as verdadeiras e assinale a alternativa CORRETA:

I – Para ventos de través, o casco principal e a superestrutura são normais ao vento e possuem o mesmo valor de resistência, então a área efetiva é aproximadamente igual a área longitudinal projetada.

II – Para ventos de proa (*head wind*) a área do casco abaixo do convés principal tem uma resistência específica bem menor do que a área frontal das superestruturas. Para propósitos práticos, a área equivalente pode ser encontrada adicionando 30% da área projetada do casco principal à área projetada da superestrutura.

III – A máxima resistência a vante é com o vento relativo de 30° da proa.

IV – Para ventos a 30° da proa, a resistência adicional ao movimento AV pode ser 30% maior quando comparados a ventos de proa (*head wind*).

(a) Todas são verdadeiras.

(b) Apenas I, II e III são verdadeiras.

(c) Apenas II, III e IV são verdadeiras.

(d) Apenas I e II são verdadeiras.

(e) Apenas III e IV são verdadeiras.

**Questão 48 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 5. **Páginas 30 a 32.**

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A typical plot of $F/(V_R)^2$ and a is shown in Fig. 28, where a is the angle between the centerline of ship and the resultant wind force. The value of $F/(V_R)^2$ is a maximum when the relative wind is on the beam, with the maximum area presented to the wind. It does not correspond with maximum wind resistance to ahead motion, since it is acting approximately at right angles to the direction of motion. As shown later, maximum wind resistance occurs when the relative wind is about 30 deg off the bow.

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For a beam wind, most of the area, both main hull and superstructure, is normal to the wind, and has the same resistance value, so that the effective area is approximately equal to the longitudinal projected area $A_L$ , Fig. 29. For a head wind, the main hull below the weather deck has a much lower specific resistance than the frontal area of the superstructures. Hughes found this ratio to be 0.31, 0.27 and 0.26 for the tanker, cargo ship and liner, respectively. For practical purposes the "equivalent area" can thus be found by adding 0.3 of the projected main hull area to the projected superstructure area, giving the transverse projected area $A_T$ (Fig. 29).

Hughes developed an equation

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These estimates apply only to a head wind and give the additional wind resistance only, ignoring any effects of the seas which would accompany high winds. For winds up to 30 deg off the bow, the additional resistance to ahead motion may be up to 30 percent greater than the values given in Table 3. The effects of streamlining will be much less for winds other than from ahead. One of the points brought out by the

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Table 3—Effects of Superstructure Changes on Speed and Power in Head Winds

| Condition | | | Tanker | Cargo Liner | Atlantic Liner |
|---|---|---|---|---|---|
| Still Air | Dispt in ton | | 16,256 | 15,037 | 38,608 |
| | Normal speed, knots | | 10 | 14 | 25 |
| | $P_E$ Bare hull, kW | | 888 | 2,072 | 25,760 |
| | Ratio as percent (still air resist/hull water resist) | With original erections | 2.5 | 2.15 | 2.1 |
| | | With streamlined erections | 1.7 | 1.55 | 1.45 |
| With 20 knots head wind | Normal erections | Ship speed, knots | 8.89 | 13.13 | 24.17 |
| | | Rel. wind in knots | 28.9 | 33.1 | 44.2 |
| | | $R_{air}/R_{water}$, percent | 26.5 | 18.5 | 7.0 |
| | Streamlined erections | Ship speed, knots | 9.25 | 13.37 | 24.42 |
| | | Rel. wind in knots | 29.25 | 33.37 | 44.42 |
| | | $R_{air}/R_{water}$, percent | 17.0 | 10.0 | 5.0 |
| | | Gain in speed, knots | 0.36 | 0.24 | 0.25 |
| With 40 knots head wind | Normal erections | Ship speed, knots | 6.73 | 11.76 | 23.27 |
| | | Rel. wind in knots | 46.7 | 51.76 | 63.3 |
| | | $R_{air}/R_{water}$, percent | 122.0 | 42.0 | 15.5 |
| | Streamlined erections | Ship speed, knots | 7.81 | 12.39 | 23.80 |
| | | Rel. wind in knots | 47.8 | 52.4 | 63.8 |
| | | $R_{air}/R_{water}$, percent | 64.0 | 27.5 | 10.4 |
| | | Gain in speed, knots | 1.08 | 0.63 | 0.53 |

**<u>Questão 49</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre o efeito do vento nos variados tipos de navios, assinale a alternativa INCORRETA:**

(a) O efeito relativo da resistência do vento é muito maior para navios lentos. Percentualmente, a perda de velocidade para ventos de proa em navios mais lentos é maior, mesmo com estruturas aerodinâmicas. Assim, maiores correções devem ser feitas para navios lentos do que para navios mais rápidos.

(b) A redução da resistência ao vento, para um vento de proa, resultante de uma boa aerodinâmica das superestruturas foi de 30%.

(c) O gradiente do vento reduzirá a força do vento em grandes quantidades, sendo maior redução para navios de passageiros.

(d) Quando um navio se move através de um local com vento natural, este possui gradiente, mas o vento criado pelo navio não. O vento relativo resultante é composto pelos dois. O gradiente efetivo, em qualquer caso, depende dos valores relativos da velocidade do vento e da velocidade do navio.

(e) Aplicando-se o gradiente do vento no ar (*still air*), as resistências do ar ficariam subestimadas em 40% e 25% para navios tanques e navios de carga na condição carregado e leve, respectivamente, e 21% para navio de passageiros. Para ventos de proa iguais a velocidade do navio, essas diferenças seriam reduzidas à metade e ainda mais para maiores ventos relativos.

**Questão 49 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 5. **Páginas 32 e 33.**

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(22 percent) and 1.2 knots (4.8 percent). Thus on a percentage basis much larger allowances are required for wind resistance in slow-speed ships than in fast ones, and streamlining should by no means be confined to the latter. In all three types of ship, the reduction in ahead-wind resistance in calm air by streamlining the erections amounts to about 30 percent.

Air-resistance information is valuable in the analysis of measured mile and voyage data and the estimation of mooring and towing forces, and the British Ship Research Association (BSRA) now British Maritime Technology (BMT), has carried out tests on models of modern counterparts of the same three types of ships as used by Hughes (1932). The superstructures were typical of present-day ships, and in no case was the streamlining excessive. The experiments were carried out in a large wind tunnel, not by towing in water. Near to the sea surface the wind is slowed down, the velocity gradient very close to the water being very steep. The tests made by Hughes did not simulate this gradient and are strictly applicable only to estimates of air resistance when the ship is moving in still air. In the BMT experiments some tests were made in a velocity gradient which compared very closely with that measured over the sea and over very smooth snow (Fig. 31).

The passenger liner had an average $K$-value of 0.59 with no velocity gradient, which compares with Hughes' value of 0.63 for a similar type of ship. In the tests with a velocity gradient the value of $K$ was reduced by some 28 percent of 0.425 using the value of $V_R$ corresponding to no gradient in each case. The average values for the tanker and cargo-ship models with the velocity gradient were 0.32 and 0.34 as compared with Hughes' figures of 0.58 and 0.6 without gradient, a reduction of about 45 percent. The wind gradient reduces the resultant wind force by appre-

**Página 33.**

ciable amounts, but less for the passenger ship with high erections which extend further into the higher wind-speed range.

When a ship is moving against a natural wind, the resultant relative wind is made up partly of the natural wind, which has a velocity gradient, and partly of the wind created by the ship's speed, which has no gradient. The effective gradient in any case therefore depends upon the relative values of wind speed and ship speed. Shearer, et al (1960) estimated that in applying their model results, obtained in a graded wind, to the case of a ship advancing into still air, the air resistance would be underestimated by some 40 and 25 percent for the tanker and cargo ships in loaded and light condition, respectively, and by about 21 percent for the passenger liner. In a head wind equal to the ship's speed, these differences would be reduced by about one half, and still more for higher relative winds.

Wilson, et al (1970) analyzed the available wind data and defined a wind drag coefficient $C_{AA0}$ for a head wind (defined as the zero relative wind heading)

**<u>Questão 50</u> – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), in a thorough analysis of the effects of wind forces on ships, Van Berlekom (1981) concluded as follows, EXCEPT:**

(a) The order of magnitude of the direct wind force on the above water structure of the ship is the same as the magnitude of the added resistance due to waves.

(b) The effect of leeway caused by wind forces is more important.

(c) The wind coefficients are in general very much dependent on the frontal and lateral areas exposed to the wind.

(d) The yawing moment on the vessel due to wind depends on the position of the main superstructure.

(e) Variations in deck house configurations are relatively of less importance with respect to the value of the wind coefficients.

**Questão 50 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 5. **Página 34.**

In a thorough analysis of the effects of wind forces on ships, Van Berlekom (1981) concluded that the order of magnitude of the direct wind force on the above-water structure of the ship is the same as the magnitude of the added resistance due to waves. The effect of leeway caused by wind forces is less important according to this study. It was also concluded that the wind coefficients are in general very much dependent on the frontal and lateral areas exposed to the wind. The yawing moment on the vessel due to wind depends on the position of the main superstructure. Variations in deck house configurations are relatively of less importance with respect to the value of the wind coefficients.

**Questão 51** – **According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), regarding added resistance due to the wave, analyze the affirmatives below and choose the CORRECT answer:**

**I – Waves approaching a ship from forward can cause appreciable added resistance.**

**II – In head seas, the added resistance is in part from the diffraction effect of the moving hull on the encountered waves and partly from the indirect effect of the pitching and heaving motions caused by the waves.**

**III – In beam and quartering seas, there may be heavy rolling and some yawing, but both of which will not be added to the resistance.**

**IV – Required rudder action do not make a significant addition.**

(a) All are true.

(b) Only I and II are true.

(c) Only III and IV are true.

(d) Only I, II and III are true.

(e) Only II, III and IV are true.

**Questão 51 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 5. **Página 34.**

**5.3 Added Resistance due to Waves.** Winds are seldom encountered at sea without wind-generated waves, sometimes from distant storms. Such waves approaching a ship from forward can cause appreciable added resistance, in part from the diffraction effect of the moving hull on the encountered waves and partly from the indirect effect of the pitching and heaving motions caused by the waves. In beam and quartering seas, there may be heavy rolling and some yawing, both of which will add to the resistance. Required rudder action may also make a significant addition. The evaluation of these effects by both model tests and theoretical calculations is discussed in Chapter VIII, Vol. III.

**<u>Questão 52</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre os regimes do fluxo nos apêndices, assinale a alternativa INCORRETA:**

(a) Quando $Rn<1x10^5$, a camada limite é totalmente laminar. Nesses Rn, as seções com moderadas a altas relações de espessura-corda mostram altos coeficientes de arrasto ($C_D$) por causa da separação da camada limite laminar (descola mais facilmente).

(b) Quando Rn está entre $1x10^5$ e $1x10^6$, há uma diminuição rápida de $C_D$, causado pela transição de laminar para turbulento para moderadas a espessas seções, separando-se mais a ré do que para o caso laminar. Para seções muito finas, na falta da separação da camada limite, essa transição de laminar para turbulento será acompanhada de um relativo aumento de $C_D$.

(c) Depois da transição de laminar para turbulento, o ponto de transição fica fixo para uma faixa de Rn até $1x10^6$, onde ele começa a se mover para vante causando um aumento leve de $C_D$.

(d) Quando $Rn>1x10^7$, o $C_D$ aumenta levemente com o aumento do Rn.

(e) Um fluxo completamente turbulento é obtido para $Rn \approx 1x10^6$ (para fluxos altamente turbulentos) e $Rn \approx 5x10^6$ (para fluxos de baixa turbulência).

**Questão 52 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 5. **Páginas 36 e 37.**

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The dependence of drag on the value of the Reynolds number has been reasonably documented for most types of two-dimensional foil sections. Fig. 34, taken from Hoerner (1965), shows the value of the drag coefficient $C_D$ as a function of Reynolds number for various types of airfoil sections of various thicknesses. Below about 1 x $10^5$ the boundary layer is completely laminar. At these Reynolds number values, sections with moderate to high thickness-chord ratios show high drag coefficients because of laminar boundary layer separation.

Between Reynolds numbers of about 1 X $10^5$ and 1 x $10^6$ the sections show a rapid decrease of their drag coefficient, caused by transition of laminar to turbulent flow which, for moderate to thick sections, separates further along the body (closer to the trailing edge), than in the case of laminar flow.

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For very thin sections, in absence of boundary layer separation, the transition from laminar to turbulent flow is accompanied by a relative increase in the value of the drag coefficient. The Reynolds number at which transition of the boundary layer occurs is termed the critical Reynolds number.

After transition of the boundary layer, the transition point remains comparatively fixed for a range of Reynolds number until, at about 1 X $10^6$, the transition point moves steadily ahead, causing the drag coefficient to increase slightly. In excess of Reynolds numbers around 1 x $10^7$ the drag coefficient decreases slightly with increasing Reynolds number.

For the sections commonly used in the design of appendages such as control surfaces (NACA 4-digit type sections for example), complete turbulent flow is usually obtained at a Reynolds number around 1 x $10^6$ in high-turbulent flow and at about 5 x $10^6$ in low-turbulent flow.

Questão 53 – According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the ultimate test of any model geosim series designed to explore appendage scale effect would be to measure the appendage resistance on the actual ship, and this was done by the British Ship Research Association on the *Lucy Ashton.* These experiments espoused by Lackenby (1955), were part of a larger program in which the old Clyde paddle steamer, 58 m long, with paddles removed, was propelled by aircraft jet engines fixed on deck, the measured thrust of which gave the ship resistance, unaffected by any interference from a towing ship. The ship results were compared with those from a series of six geosim models. In this manner, regarding the aforementioned experiment, analyze the affirmatives below and choose the CORRECT answer:

I – Streamline-flow experiments on a model indicated that the best angle for the bossings would be 40 deg to the horizontal. These showed an increase of only 3 to 4 percent in resistance on the model, which was considered too small for accuracy in the type of experiments involved.

II – The bossings were therefore fitted at 20 deg, being across the flow, and the increase in resistance was thereby doubled. The wetted surface of the bossings was only 2 percent of that of the bare hull. The percentage increase in resistance measured on the ship was fairly constant at about 5 percent up to 12 knots, after which it declined to almost nothing at 15 knots.

III – The increase due to the A-brackets and open shafts was reasonably constant at about 3% percent.

IV – The geosim models were tested at NPL and had lengths of 2.74, 3.66, 4.88, 6.10, 7.32 and 9.14 m. The increase in resistance due to appendages never exceeded 7 percent of the barehull resistance.

(a) All are true.

(b) Only I, II and III are true.

(c) Only II, III and IV are true.

(d) Only I and II are true.

(e) Only III and IV are true.

**Questão 53 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 5. **Página 40.**

The ultimate test of any model geosim series designed to explore appendage scale effect would be to measure the appendage resistance on the actual ship, and this was done by the British Ship Research Association on the *Lucy Ashton*. These experiments espoused by Lackenby (1955), were part of a larger program in which the old Clyde paddle steamer, 58 m long, with paddles removed, was propelled by aircraft jet engines fixed on deck, the measured thrust of which gave the ship resistance, unaffected by any interference from a towing ship. The ship results were compared with those from a series of six geosim models.

Dummy appendages were fitted aft, and measured mile trials carried out with bare hull, with open shafts and struts and with full bossings. Streamline-flow experiments on a model indicated that the best angle for the bossings would be 40 deg to the horizontal. These showed an increase of only 3 to 4 percent in resistance on the model, which was considered too small for accuracy in the type of experiments involved. The bossings were therefore fitted at 20 deg, being across the flow, and the increase in resistance was thereby doubled. The wetted surface of the bossings was only 2 percent of that of the bare hull. The percentage increase in resistance measured on the ship was fairly constant at about 5 percent up to 12 knots, after which it declined to almost nothing at 15 knots. The increase due to the A-brackets and open shafts was reasonably constant at about 3% percent.

The geosim models were tested at NPL and had lengths of 2.74, 3.66, 4.88, 6.10, 7.32 and 9.14 m. The increase in resistance due to appendages never exceeded 7 percent of the barehull resistance.

**<u>Questão 54</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), assinale a alternativa INCORRETA:**

(a) Em baixas velocidades existe um afundamento geral e um pequeno trim pela popa comparado com a posição de repouso.

(b) Conforme a velocidade aumenta, a proa começa a subir apreciavelmente e a popa afunda ainda mais, e o navio toma um decidido trim pela popa.

(c) Em navios de grande deslocamento, reduções de resistência que podem ser efetuados pela mudança de trim são muito pequenas. Porém, em navios de alta velocidade, a posição do centro de gravidade e o trim resultante tem maior influência na performance.

(d) Na média dos navios mercantes, trim adicional pela popa, na condição de repouso, normalmente resulta em aumento de resistência a baixas velocidades e diminuição de resistência a altas velocidades.

(e) Em baixas velocidades, um trim pela popa faz a popa ficar virtualmente mais cheia, com consequente aumento de resistência de forma e separação. Em altas velocidades isso é mais que compensado pela redução em *wave-making* devido às entradas mais finas.

**Questão 54 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 5. **Páginas 41 e 42.**

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5.5 **Trim Effects**. Owing to the change in pressure distribution around a ship at different speeds, it will rise or sink bodily and also trim. At low speeds there is a general sinkage and a slight trim by the bow as compared with the at-rest condition (Fig. 41.) As speed increases the movement of the bow is reversed and at Fn = 0.30 or thereabouts the bow begins to rise appreciably, the stern sinks still further and the ship takes on a decided trim by the stern (Fig. 42).

As D.W. Taylor (1943) pointed out, large trim changes or sinkage of the center of gravity are symptoms rather than causes of high resistance. Nevertheless they may indicate the desirability of altering the at-rest trim by shifting the center of gravity longitudinally. The reductions of resistance which can be effected by such changes of trim as are practicable in large displacement craft are very small, but in high-speed planing craft the position of the center of gravity and the resultant still-water trim have a most important influence on performance. In both cases the possible effects can be investigated on model scale.

In the average merchant-ship form, additional trim by the stern in the at-rest condition usually results in an increase in resistance at low speeds and a decrease at high speeds. At low speeds the increased draft aft makes the stern virtually fuller, with a consequent increase in form and separation resistance, whereas

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at high speeds this is more than offset by the reduction in wave-making due to the finer entrance in the trimmed condition.

**<u>Questão 55</u> – Considerando a condição de um navio que demanda a entrada no porto totalmente carregado, com a situação em que o navio demanda a saída do porto descarregado e em lastro, de acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), podemos AFIRMAR que na saída:**

(a) A área molhada por unidade de deslocamento é reduzida.

(b) A resistência friccional é reduzida.

(c) A resistência residual aumenta.

(d) A resistência por unidade de deslocamento será menor.

(e) A velocidade será maior na mesma potência.

**Questão 55 – Resposta:** Letra E

**Comentário:** PNA. Chapter V. Section 5. **Página 42.**

In ballast condition, at level trim, the wetted surface per unit of displacement is much increased, so that the frictional resistance is increased also, but because of the finer form at the reduced draft, the residuary resistance is decreased. In general, except in high-speed ships, the total resistance per unit of displacement will be greater, but because of the lower displacement the total resistance and power will be reduced, and the ship in ballast will make a higher speed at the same power.

In ballast condition it is usually necessary to carry considerable trim by the stern in order to ensure adequate immersion of the propeller, and this will have similar effects to those stated in the foregoing—higher resistance at low speeds, less at high speeds. For any ship which is likely to spend an appreciable part of her time at sea in ballast condition, model experiments are usually made to investigate these effects.

**<u>Questão 56</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), sobre os efeitos de águas rasas, assinale a alternativa INCORRETA:**

(a) Em águas rasas, a velocidade do fluxo abaixo do navio aumenta, consequentemente reduzindo a pressão, aumentando o afundamento, trim e resistência.

(b) Há mudança no padrão de ondas quando saindo de águas profundas para águas rasas.

(c) A resistência é máxima quando se alcança a velocidade crítica. Nessa velocidade a resistência é muito maior em águas rasas que em águas profundas.

(d) Para manter o mesmo padrão de ondas de águas profundas quando navegando em águas rasas, o navio deve navegar com velocidade maior.

(e) Quanto mais raso for o local, os *humps and hollows* ocorrem a velocidades menores.

**Questão 56 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 5. **Páginas 42 a 44.**

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**5.6 Shallow-Water Effects.** The resistance of a ship is quite sensitive to the effects of shallow water.

In the first place there is an appreciable change in potential flow around the hull. If the ship is considered as being at rest in a flowing stream of restricted depth, but unrestricted width, the water passing below it must speed up more than in deep water, with a consequent greater reduction in pressure and increased sinkage, trim and resistance. If in addition the water is restricted laterally, as in a river or canal, these effects are further exaggerated. The sinkage and trim in very shallow water may set an upper limit to the speed at which ships can operate without touching bottom.

A second effect is the changes in the wave pattern which occur in passing from deep to shallow water. These changes have been studied by Havelock (1908) for a point pressure impulse travelling over a free water surface.

When the water is very deep, the wave pattern consists of the transverse and diverging waves shown in Fig. 6, the pattern being contained between the straight lines making an angle a of 19 deg 28 min on each side of the line of motion of the point.

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The effect upon resistance due to these changes in wave pattern in shallow water has been investigated by Havelock (1908) for a pressure disturbance of linear dimension $l$ travelling over water of depth $h$. The resistance curves are reproduced in Fig. 44. Each curve is marked with the value of the ratio of depth of water $h$ to the characteristic length of the disturbance $l$, that marked $\infty$ being for deep water. When the ratio $h/l$ is 0.75, there is a marked peak at a speed corresponding to a value of $V/\sqrt{gl} = 0.86$. Since $\sqrt{h/l} = 0.866$, this corresponds to a value of unity for $V/\sqrt{gh}$, so that the peak corresponds to the speed of the wave of translation for that particular depth of water, or the critical speed. At this speed the resistance is very much greater than in deep water, but ultimately at a sufficiently high speed it becomes less than in deep water. This depth effect has an important bearing on full-scale ship trials, and can cause misleading results on

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the relation between power and speed.

Speeds below and above $V = \sqrt{gh}$ are referred to as subcritical and supercritical, respectively. Nearly all displacement ships operate in the subcritical zone, the exceptions being destroyers, cross-channel ships and similar types. It is seen from Equation (32) that as the depth of water decreases the speed of a wave of given length decreases also. Thus to maintain the same wave pattern a ship moving in shallow water will travel at a lower speed than in deep water, and the humps and hollows in the resistance curve occur at lower speeds the shallower the water.

**<u>Questão 57</u> – O NM OREOIL, de 200 metros de comprimento, 20 metros de boca e 12 metros de calado, estava navegando a 30 nós em um local de 22,5 metros de profundidade. De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), assinale a alternativa CORRETA (considere g = 10 m/s² e 1 nó = 0,5 m/s):**

(a) O padrão de ondas irradiado pelo NM OREOIL é idêntico ao que se estivesse em águas profundas.

(b) O padrão de ondas irradiado pelo NM OREOIL consiste em ondas transversais e divergentes, contudo o ângulo entre as linhas retas que contém o padrão de ondas divergentes não é mais o mesmo que seria se estivesse em águas profundas.

(c) O padrão de ondas irradiado pelo NM OREOIL está concentrado em uma única crista que possui ângulo de 90° com a direção do movimento. Toda energia do sistema é transmitida com a onda.

(d) O padrão de ondas irradiado pelo NM OREOIL consiste apenas de ondas transversais que viajam na mesma velocidade e direção que o NM.

(e) O padrão de ondas irradiado pelo NM OREOIL consiste apenas de ondas divergentes que apresentam as cristas com a concavidade voltada para a linha da direção de movimento do NM.

**Questão 57 – Resposta:** Letra C

**Comentário:** PNA. Chapter V. Section 5. **Página 43.**

For speeds less than $V = \sqrt{gh}$, the system consists of a double set of waves, transverse and diverging as in deep water, advancing with the pressure point at velocity $V$. For values of $V$ less than about $0.4\sqrt{gh}$, the pattern is enclosed between the straight lines having an angle a = 19 deg 28 min to the centerline, as for deep water. As $V$ increases above this value, the angle $\alpha$ increases and approaches 90 deg as $V$ approaches $\sqrt{gh}$, Fig. 43.

The pressure point is now generating a disturbance which is travelling at the same speed as itself, and all the wave-making effect is concentrated in a single crest through the point and at right angles to its direction of motion. This pattern agrees with observations on models and ships when running at the critical velocity in shallow water. The whole of the energy is transmitted with the wave, and the wave is called a *wave of translation.*

When $V$ exceeds $\sqrt{gh}$, $\alpha$ begins to decrease again, the wave system being contained between the lines given by $\sin^2\alpha = gh/(V)^2$, Fig. 43. It now consists only of diverging waves, there being no transverse waves or cusps. The two straight lines themselves are the front crests of the diverging system, and the inner crests are concave to the line of advance instead of convex as in deep water.

The effect upon resistance due to these changes in wave pattern in shallow water has been investigated by Havelock (1908) for a pressure disturbance of linear dimension $l$ travelling over water of depth $h$. The resistance curves are reproduced in Fig. 44. Each curve is marked with the value of the ratio of depth of water $h$ to the characteristic length of the disturbance $l$, that marked $\infty$ being for deep water. When the ratio $h/l$ is 0.75, there is a marked peak at a speed corresponding to a value of $V/\sqrt{gl} = 0.86$. Since $\sqrt{h/l} = 0.866$, this corresponds to a value of unity for $V/\sqrt{gh}$, so that the peak corresponds to the speed of the wave of translation for that particular depth of water, or the critical speed. At this speed the resistance is very much greater than in deep water, but ultimately at a sufficiently high speed it becomes less than in deep water. This depth effect has an important bearing on full-scale ship trials, and can cause misleading results on

**Questão 58** – **According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), when the speed of a ship in shallow water approaches and passes the critical speed, radical changes occur in the wave pattern around the ship, in the ship's attitude, and in its resistance. Thus, analyze the affirmatives below and choose the CORRECT answer:**

**I – As the speed of the model approaches the critical speed the resistance begin to increase very rapidly.**

**II – When the critical speed is passed the trim falls off very quickly**

**III – When the critical speed is passed the resistance starts to fall off slowly.**

**IV – Right after critical speed is passed, the shallow water resistance will be smaller than deep water resistance.**

(a) All are true.

(b) Only I, II and III are true.

(c) Only II, III and IV are true.

(d) Only I and II are true.

(e) Only III and IV are true.

**Questão 58 – Resposta:** Letra D

**Comentário:** PNA. Chapter V. Section 5. **Página 49.**

The characteristic behavior of a high-speed ship in shallow water is illustrated in Fig. 53, which shows resistance and trim curves for a model of a destroyer run in different depths of water (Rota, 1900). On each curve is marked the *critical speed* where the value of $V/\sqrt{gh}$ is unity for that particular depth. Considering the curves for the shallowest depth, where the ratio (depth of water) / (draft of ship) is 3.08, it will be seen that as the speed of the model approaches the critical speed the trim by the stern and the resistance both begin to increase very rapidly. When the critical speed is passed the trim falls off very quickly and the resistance remains almost constant for a time before beginning to increase again but then at a somewhat lower rate than in deep water. Finally, at a $V/\sqrt{gL}$ of about 0.48 both the trim and resistance curves cross those for deep water, and above this speed, now well in the supercritical zone, the resistance and trim are both less than in deep water.

**Questão 59** – **Observations of the wave pattern on the trials of the destroyer HMS *Cossack* (Watts, 1909) showed that in deep water the stern wave increased in size continuously with increase in speed. On the shallow measured mile course, however, it increased very rapidly in size up to about 22 knots and then appeared to become unstable and fell away to about half its maximum height. At 28 knots the stern wave had practically disappeared and did not re-appear during the higher speed runs. This changing pattern is generally in accord with that described by Havelock for pressure disturbances. According to the book "Principles of Naval Architecture" (SNAME – 3rd edition: 1988/1989), the effects of shallow water are first noticed on HMS Cossack at speed of, approximately:**

(a) 11 knots

(b) 15 knots

(c) 17 knots

(d) 19 knots

(e) 22 knots

**Questão 59 – Resposta:** Letra B

**Comentário:** PNA. Chapter V. Section 5. **Página 49.**

The typical characteristics of shallow-water behavior found in such model experiments are well borne out in full-scale trials (Watts, 1909). The speeds at which the power begins to increase, that is, where the effects of shallow water are first noticed, can be given approximately by the relation

$$V_K = 4.17\sqrt{h},\ h \text{ in meters} \quad (52)$$

This formula may therefore be used with some confidence to calculate the speed at which the wave making resistance in shallow water begins to increase appreciably as the critical speed is approached. The critical speed is given by

$$V_K = 6.09\sqrt{h},\ h \text{ in meters} \quad (53)$$

The ratio of the speed at which the power begins to increase (Equation (52)) to the critical speed is 4.17/6.09 or 0.68. Observations of the wave pattern on the trials of the destroyer HMS *Cossack* (Watts, 1909) showed that in deep water the stern wave increased in size continuously with increase in speed. On the shallow measured mile course, however, it increased very rapidly in size up to about 22 knots and then appeared to become unstable and fell away to about half its maximum height. At 28 knots the stern wave had practically disappeared and did not re-appear during the higher speed runs. This changing pattern is generally in accord with that described by Havelock for pressure disturbances.

Como a velocidade crítica é 22 nós (descrita pela característica da onda gerada pelo navio no experimento), a velocidade que o efeito de águas rasas começa a ser sentido é: 22 x 0,68 = 15 nós.

**<u>Questão 60</u> – De acordo com o contido no livro "Principles of Naval Architecture" (SNAME – 3ª edição: 1988/1989), assinale a alternativa INCORRETA:**

(a) O aumento em resistência em navios que tem um *yaw* fixo e/ou um ângulo de adernamento é mais marcante em navios a vela (*sailing ships*) e barcos a vela (*yatchs sailing*) velejando para sotavento.

(b) Para embarcação a vela (*sailing vessel*) completamente simétrico, a única forma que forças hidrodinâmicas podem se desenvolver é quando o casco adota um ângulo de ataque relativo ao seu rumo na água.

(c) Ângulos de deriva (*leeway*) típicos são 3° a 6°, embora *yatchs* com pequenas quilhas, grandes ângulos de deriva podem se desenvolver. Ângulos de adernamento (*heel angle*) de até 30° são normais.

(d) Para outros navios, *yaw angle* também pode ocorrer por causa de propriedades assimétricas do casco, tais como *shaft brackets* ou outros apêndices, estão desalinhados. Nestes casos, um pequeno e constante ângulo de leme é necessário para compensar os resultados da força hidrodinâmica. Contudo, nesse caso um momento hidrodinâmico é exercido no navio que tem que ser contrabalanceado pelo casco, adotando um ângulo de deriva (*leeway*), normalmente de 1° a 2°.

(e) O aumento de resistência devido a ângulo de deriva (*leeway*) menor que cerca de 5° é quase que totalmente devido à resistência induzida, com a produção de força lateral ou *lift* do casco.

**Questão 60 – Resposta:** Letra A

**Comentário:** PNA. Chapter V. Section 5. **Páginas 50 e 51.**

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special reference to sailing yachts. The increase in resistance that occurs when a ship has a fixed yaw and or a heel angle is most marked in sailing ships and yachts sailing to windward. Steady yaw angles usually occur when the vessel has to counteract some aerodynamic side force on the superstructure or sails by developing an equal and opposite hydrodynamic side force on the hull and on the keel. For a sailing vessel with completely symmetrical hull the only way hydrodynamic side forces can develop is when the hull adopts an angle of attack relative to its course through the water. In sailing yachts this angle is usually referred to as leeway. The same aerodynamic force on the superstructure or the sails will also cause a heel angle for yachts sailing to windward. Typical leeway angles are between 3 and 6 degrees, although on yachts with inefficient keels (i.e. keels which do not possess the characteristic of being able to develop the required side force at small angles of leeway) larger leeway angles may occur. Heel angles of up to 30 degrees are quite normal. For other ships yaw angles can also occur because of unsymmetrical properties of the hull, such as can occur when shaft brackets or other appendages are misaligned. In those cases a constant

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(usually small) rudder angle is required to compensate for the hydrodynamic side force that results. However, in that case a hydrodynamic moment is exerted on the vessel which has to be counterbalanced by the hull adopting some leeway angle. In these cases, however, angles are usually within 1 or 2 degrees.

The resistance increase due to leeway angles less than about 5 degrees is almost entirely due to the so-called induced resistance associated with the production of side force or lift on the hull. Lift is generated by deflecting a flow over an angle $\alpha_i$ downward (or sideways) from its undisturbed direction. The force generated by the body that induces (deflects) this flow is directed at approximately right angles to the direction of the deflected flow, as shown in Fig. 55. It follows that the component of this force, $F \sin \alpha_i$, then acts against the direction of motion. This force is called the induced drag force $R_i$ because it is associated with the induced flow field. From Fig. 55 it follows that $R_i = F \sin \alpha_i = L \tan \alpha_i$. Hence $C_{R_i} = C_L \tan \alpha_i$. It can be shown that the induced flow angle $\alpha_i$ is related to the lift coefficient and the aspect ratio according to:

## GABARITO

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
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