THE OCEAN ENVIRONMENT AND PHENOMENA

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Overview

A ship is designed for a purpose. This may be:

To give pleasure to a yachtsman;
To deploy a weapons system;
To carry cargo or passengers;
To provide a service.

To fulfill this purpose the ship must:

Have enough internal capacity to contain everything requiring to be stowed in the ship. Be divided internally into compartments serving a specific function (e.g. machinery space, accommodation, cargo holds etc). Each compartment must be of a size suitable for its function, must be positioned suitably within the ship in relation to other compartments (e.g. a galley adjacent to a dining saloon) and accessible via appropriate passage and stairways. Each compartment must be suitably equipped.

Float at its designed waterline when fully loaded, and float reasonably level. This is important from the point of view of seaworthiness and maneuverability. Excessive trim bow or stern down will make steering difficult and may result in excessive amounts of water coming on deck in rough weather. The draught to which a merchant ship may be loaded is governed by law.

The ship must be stable and float upright in calm water. It should also be safe from capsize in rough weather. The ship should be stable in all conditions of loading and should be capable of sustaining a reasonable degree of damage (resulting in partially flooding the hull) without sinking or becoming unstable. The hull must be so shaped that it does not require an excessive amount of propulsion power to achieve its service speed. The hull must be so shaped that it does not pitch, roll or heave excessively in rough weather, and so that it does not get excessive amounts of water on deck or experience slamming damage. The hull structure must be strong enough to sustain the loads applied to it in service. The structure must not vibrate excessively. The structure should not deteriorate too rapidly in service (e.g. through corrosion).

The power installed in the ship must be adequate for the required service speed and there must be enough fuel capacity for the required operating range. The vessel must represent value for money i.e. is so designed as to maximize return on capital invested. Hence with all these drivers in mind the first part of the book is tackled which is that of the environment.

1. Properties: Fresh Water; Salt Water; Air

1.1. Water

Two of the most important variables in seawater are temperature and salinity (the concentration of dissolved salts). The two quantities work in conjunction to control the density of seawater. Since the composition of seawater is affected mainly by the addition of dissolved salts brought to it by the rivers, volcanic eruptions, erosion of rocks, and many other ways, the composition differs from one region to the next.

The physical properties of seawater are quite different from those of freshwater. The presence of various salts make seawater undrinkable The total dissolved salts in seawater are approximately 34.4 g/l, some 300 times that of river water. The main dissolved constituents in seawater include sodium and chloride. Since salt ions are heavier than water molecules, seawater is denser than freshwater. The density of seawater ranges from 1020 to 1030 kg/m$^{\mathbf{3}}$ while the density of freshwater is about 1000 kg/m$^{\mathbf{3}}$. Variations in salinity also cause the freezing point of seawater to be somewhat lower than that of freshwater. Freshwater freezes at zero degrees Celsius. Since salt ions interfere with the formation of hydrogen bonds, seawater does not have a fixed freezing point.

Often in calculations of ship hydrostatics a standard sea water density of 1025 kg/m^3 is used. However, if the ship is to operate in other water courses that are fresh or brackish then the appropriate water density for this situation is used.

The density is much more temperature dependent, freshwater density generally decreasing as the temperature increases, with a maximum at about 4^0C. Salinity also influences water density. Away from coasts the salinity of ocean water varies from 32 − 37 ppm. The variations in salinity result from the differences in the relative rates of precipitation and evaporation from the ocean surface. Ocean water does not show the anomalous thermal expansion of freshwater. The density decreases monotonically with increasing temperature, right from the freezing point. When temperature and pressure are constant, density of sea water increases with salinity. A difference of 1 ppm in salinity has an effect on the density of sea water which is about five times greater than the change caused by 1^0C of temperature. The large scale density structure of the ocean is dominated by variations in temperature, while salinity differences have more effect on smaller scale motions. The densest waters are formed off Greenland and in the Norwegian Sea. Dividing by density ρ shows that in the fundamental equation of motion the viscosity appears in the ratio μ / ρ. This is the kinematic molecular viscosity ν :

$$\nu = \frac{\mu}{\rho}$$

Typical values for air and water are such that $\mu_{\text{air}} / \mu_{\text{water}}$ 1.8 × 10−2.

However $\rho_{\text{air}} / \rho_{\text{water}} = 1.2 \times 10^{-3}$, and calculating the ratio of the kinematic viscosities gives:

$$\nu_{\text{air}} / \nu_{\text{water}} = 15 .$$

Hence we find that in its effect on the flow patterns, air is fifteen times more viscous than water!
The kinematic viscosity for sea water of salinity $S = 35\text{ppm}$ and temperature $T =$ 20$^{\text{o}}$C is 1.064×10^{-6} m^2 s^{-1}.

Temperature	Pressure	Density	Dynamic Viscosity
^{0}C	Pa	kgm^{-3}	$kgm^{-1}s^{-1}$
0.00	101325	999.82	0.001792
1.00	101325	999.89	0.001731
2.00	101325	999.94	0.001674
3.00	101325	999.98	0.001620
4.00	101325	1000.00	0.001569
5.00	101325	1000.00	0.001520
6.00	101325	999.99	0.001473
7.00	101325	999.96	0.001429
8.00	101325	999.91	0.001386
9.00	101325	999.85	0.001346
10.00	101325	999.77	0.001308
11.00	101325	999.68	0.001271
12.00	101325	999.58	0.001236
13.00	101325	999.46	0.001202
14.00	101325	999.33	0.001170
15.00	101325	999.19	0.001139
16.00	101325	999.03	0.001109
17.00	101325	998.86	0.001081
18.00	101325	998.68	0.001054
19.00	101325	998.49	0.001028
20.00	101325	998.29	0.001003
21.00	101325	998.08	0.000979
22.00	101325	997.86	0.000955
23.00	101325	997.62	0.000933
24.00	101325	997.38	0.000911
25.00	101325	997.13	0.000891

Table 1. Properties of fresh water

Temperature	Salinity/(g kg^{-1})				
	20	25	30	35	40
^{0}C	ρ /kg m^{-3}				
0	1016.04	1020.06	1024.08	1028.10	1032.14
5	1015.84	1019.78	1023.73	1027.68	1031.64
10	1015.31	1019.18	1023.07	1026.96	1030.86
15	1014.48	1018.30	1022.13	1025.97	1029.82
20	1013.39	1017.17	1020.96	1024.75	1028.56
25	1012.07	1015.82	1019.57	1023.34	1027.12

Table 2. Density ρ of sea water at atmospheric pressure Kaye & Laby 2005

Property	$0\,^{0}C$	$20\,^{0}C$
Dynamic viscosity	1.88×10^{-3} Pa s	1.08×10^{-3} Pa s
Kinematic viscosity, ν	1.83×10^{-6} m^2 s^{-1}	1.05×10^{-6} m^2 s^{-1}
Thermal conductivity	0.563 W m^{-1} K^{-1}	0.596 W m^{-1} K^{-1}
Thermal diffusivity, κ	1.37×10^{-7} m^2 s^{-1}	1.46×10^{-7} m^2 s^{-1}
Prandtl number, ν / κ	13.4	7.2
Specific heat capacity, C_p	3985 J kg^{-1} K^{-1}	3993 J kg^{-1} k^{-1}
Thermal expansion coefficient Pressure = 0.1 MN m^{-2} Pressure = 100 MN m^{-2}	 52×10^{-6} K^{-1} 244×10^{-6} K^{-1}	 250×10^{-6} K^{-1} 325×10^{-6} K^{-1}
Ratio of specific heat capacities, C_p/C_v	1.000 4	1.010 6
Velocity of sound	1449 m s^{-1}	1522 m s^{-1}
Compressibility	4.65×10^{-10} Pa^{-1}	4.28×10^{-10} Pa^{-1}
Freezing point		$-1.910\ ^{0}C$
Boiling point		$100.56\ ^{0}C$

Table 3. Mechanical and thermal properties of sea water at salinity 35 g kg^{-1} and atmospheric pressure (unless otherwise stated) Kaye & Laby 2005

Temperature $t\ ^{0}C$	Density ρ kg/m^3	Specific heat capacity C_p kJ/kg K	Kinematic Viscosity ν m^2/s x 10^{-6}
-150	2.793	1.026	3.08
-100	1.980	1.009	5.95
-50	1.534	1.005	9.55
0	1.293	1.005	13.30
20	1.205	1.005	15.11
40	1.127	1.005	16.97
60	1.067	1.009	18.90
80	1.000	1.009	20.94
100	0.946	1.009	23.06
120	0.898	1.013	25.23
140	0.854	1.013	27.55
160	0.815	1.017	29.85
180	0.779	1.022	32.29
200	0.746	1.026	34.63

Table 4. Properties of Air (Kaye & Laby 2005)

In heavy storms, the waves and ship motions can become so large that water flows onto the deck of a ship. This problem is termed as *shipping of water*, *deck wetness* or *green water loading*. The term *green water* is used to distinguish between the spray which is in reality, small amounts of water and foam flying around and the real solid seawater on the deck. When the wave relative to the ship motion does not ship green water onto the deck there can be another effect on a ship i.e. slamming. Such an impact between the water and a ship can cause important local and global loads on the vessel. Slamming on ship hulls is often categorized as bottom slamming and bow flare slamming. When a bow flare section of a ship enters the water, the local loads around the flare are not influenced by hydroelasticity.

1.2. Air

Air is a mixture of gases, predominantly nitrogen (78%) and oxygen (21%) with traces of water vapor, carbon dioxide, argon, and various other components. Air is usually modeled as a uniform (no variation or fluctuation) gas with properties that are averaged from all the individual components.

The values and relations of the properties define the state of the gas. The pressure, p of a gas equals the perpendicular (normal) force exerted by the gas divided by the surface area on which the force is exerted. A gas can also exert a tangential (shearing) force on a surface, which acts like friction between solid surfaces. This frictional property of the gas is called the viscosity, μ and it plays a large role in aerodynamic drag. The same is also true for the frictional coefficient of water and its effect on hydrodynamic drag. The temperature, T of a gas is a measure of the kinetic energy of the gas.

The density (specific volume), pressure, and temperature of a gas are related to each other through the equation of state. There is a universal gas constant which relates these variables and the molecular weight of any gas. Including the value of the molecular weight, we can define a particular gas constant (R) for air. The state of a gas can be changed by external processes, and the reaction of the gas can be predicted using the laws of thermodynamics. Studies of the zeroth and first laws introduce the idea of the heat capacity of a substance. The specific heat of a gas is a measure of the amount of energy necessary to raise the temperature of the gas by a single degree. Since the amount depends on the process used to raise the temperature, there is a specific heat (C_{v}) coefficient for a constant volume process, and a different valued coefficient for a constant pressure (C_{p}). The symbol γ denotes the ratio of these coefficients.

Typical values of the density, pressure, and temperature of air at sea level static conditions for a standard day are:

- Density: 1.229 kg/m^3 (00237slug/ft^3)
- Specific Volume: 0.814 m^3/ kg (422 ft^3/ slug)
- Pressure: 101.3 kPa(14.7 lbs/in^2)
- Temperature: 15$^{\mathrm{o}}$C (59$^{\mathrm{o}}$F)
- Absolute Temperature: 288$^{\mathrm{o}}$K (519$^{\mathrm{o}}$R)
- Viscosity: 173 cP
- Gas Constant: 0.286 J/g $^{\mathrm{o}}$K.
- Specific heat at constant volume C_{v}: 0.715 J/g $^{\mathrm{o}}$K .

Values given in the table are based on the standard atmosphere of the International Aviation Organization (ICAO). They are representative of average atmospheric conditions in temperature latitudes

1.3. Ice

Ice is the state of fresh water below zero degrees centigrade. When we consider the icing of salt water the problem becomes quite complicated. This is a small summary of the vast amount of literature on the study of sea-ice.

When ice grows in the sea the first year growth is significant. It differs in two ways from that of fresh water. Firstly, salt reduces the freezing point of water according to:

$$T_{\mathrm{f}} = 0.003 - 0.0527 S_{\mathrm{w}} - 0.00004 S_{\mathrm{w}}^2$$

Where T_{f} is the freezing temperature, S_{w} is the salinity of the water in parts per thousand. Secondly, the temperature of the maximum density of seawater for salinities greater than 24.7% is less than the freezing point. This results in cooling of seawater in this salinity range producing an unstable vertical density distribution. This leads to continued overturning that continues until the water reaches the freezing point. Because of the sea water density structure this convection s limited to a relatively shallow layer. This well mixed layer, which is between 10m and 40m thick, must to the freezing point before freezing starts again. Initial ice formation begins at the water surface where heat loss is greatest. This provides a small amount of super cooling necessary for ice to grow. The growth starts with the formation of small platelets and needles, called frazil. As the frazil crystals continue to form a mixture of unconsolidated crystals and sea water is created, often called grease ice. With further freezing under good conditions, the frazil begin to coalesce to form a solid cover about 10cm thick. This ice which behaves elastically is called nilas. In large open areas of say, the Arctic or Antarctic wind and wave action causes the formation of pancake ice which consists of circular masses of semi-consolidated frazil. These pancakes have diameters in the range 0.3m to 3.0m. These also develop raised rims from constant movement between each other and the resulting sloshing of newly formed crystals between the pancakes eventually forming either a solid ice sheet or a solid pancake. Table 5 gives some properties of ice.

Temperature *T*	Density *ρ*	Thermal Conductivity *k*	Specific Heat c_p
$^o C$	kg/m^3	*W/mK*	*kJ/kgK*
0	916.2	2.22	2.050
-5	917.5	2.25	2.027
-10	918.9	2.30	2.000
-15	919.4	2.34	1.972
-20	919.4	2.39	1.943
-25	919.6	2.45	1.913
-30	920.0	2.50	1.882

Table 5. Ice Properties was a function of temperature

2. Water Waves

Waves at sea are generated by the wind, which might be self evident since on windy days the sea is rough. Waves are the response made by the water as gravity on a large scale, or surface tension on the micro-scale try to restore the surface back to its original level before the wind disturbed it. The size of the waves, both in terms of length or height increases with the time for which the wind is blowing and also the length of water surface over which the wind blows, also called the fetch. The first waves generated by the wind are very short in length maybe no more than 10mm and are due to the effects of surface tension on the water surface. Gradually as the length of the waves increase the effect of gravity takes over as the restoring force. As the wind persists, the wave height normally referred to as the vertical distance between the bottom of a trough and the top of a nearby crest increases. The wavelength, which we might take to be the distance between prominent crests, is around 50m - 800m. Watching the waves for a few minutes, it is noticed that wave-height and wave-length are not constant. The actual heights vary randomly in time and space, and the statistical properties of the waves, such as the mean height averaged for a few hundred waves, change from day to day. When the wind ceases the waves are still present. In the big oceans of the world these waves can travel hundreds of kilometers and are often called swell waves. These waves produce breaking waves on the beach when there may have been no wind for days.

If the sea is observed for a protracted period of time there is a slow change in the average level of the water. This slow rise and fall of sea level is due to the tides, another type of wave on the sea surface. Tides have wavelengths of thousands of kilometers, and they are generated by the motion of the Sun and the Moon relative to Earth. All these different wav types are illustrated in Table 6.

WAVE	PERIOD	WAVELENGTH	WAVE TYPE	CAUSE
Capillary	< 0.1 sec	< 2 cm	deep to shallow	local winds
Chop	1-10 sec	1-10 m	deep to shallow	local winds
Swell	10-30 sec	up to hundreds of m	deep or shallow	distant storm
Seiche	10 min-10 hr	up to hundreds of km	shallow or intermediate	wind, tsunami, tidal resonance
Tsunami	10-60 min	up to hundreds of km	shallow or intermediate	submarine disturbance i.e. earthquakes or volcanic eruptions under (or near) the ocean
Tide	12.4-24.8 hr	thousands of km	shallow	gravitational attraction of sun and moon

Table 6. Classification of wave types

2.1. Linear Theory of Ocean Surface Waves

To solve the problem of the prediction of wave motion there is an apparent paradox. Surface waves are inherently nonlinear. The solution of the equations of motion depends on the surface boundary conditions, but the surface boundary conditions are the waves we wish to calculate.

To solve this problem it is assumed that the amplitude of waves on the water surface is infinitely small so the surface is almost exactly a plane. To simplify the mathematics, it is also assumed that the flow is two dimensional with waves travelling in the x – direction. It can also be assumed that the Coriolis force and viscosity can be neglected.

With these assumptions, the sea-surface elevation ζ of a wave travelling in the x – direction is:

$$\zeta = a\sin(kx - \omega gt) \tag{1}$$

With

$$\omega = 2\pi f = \frac{2\pi}{T}; k = \frac{2\pi}{\lambda} \tag{2}$$

Where, ω is wave frequency in radians per second, f is the wave frequency in Hertz (Hz), k is wave number, T is wave period, λ is wave-length. This is shown in Figure 1 (Holmes, 2001)

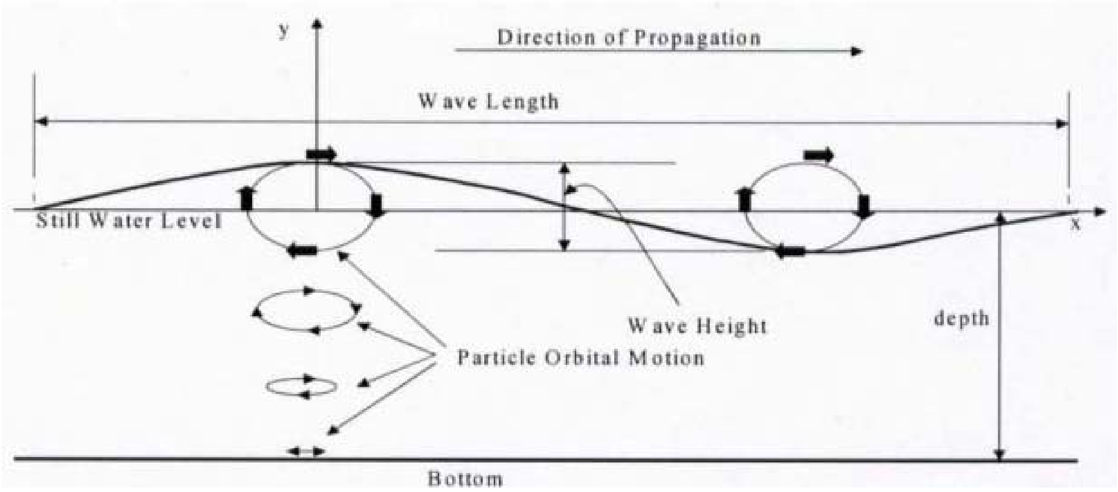

Figure 1. Regular wave properties (Holmes, 2001)

The *wave period T* is the time it takes two successive wave crests or troughs to pass a fixed point. The *wave-length* λ is the distance between two successive wave crests or troughs at a fixed time.

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Biographical Sketch

Philip Wilson was born in the Staffordshire, England July 1947. He was educated at grammar schools in Sheffield and Hull and then attended the University of Leicester from where he graduated with a BSc. first class honours degree in Mathematics in June 1968. He was further awarded a DSc from the University of Leicester for his work in Hydrodynamics and Naval Architecture in June 2007. He is a Fellow of the Royal Institution of Naval Architects (FRINA), January 2007 and a Chartered Engineer (CEng). 1980.

He has worked previously at Plessey Underwater Noise Unit where he developed theories to explain the transmission of sound through structures and water. Following a short period at The British United Shoe Machinery Co in Leicester where he worked as a management statistician, he has been at the University of Southampton, Southampton, England since January 1973. He was a founding member of the Department of Ship Science. Currently he is Professor of Ship Dynamics.

He currently is the editor of the International Journal of Maritime Engineering the journal of the Royal Institution of Naval Architects. He lectures on the Ship Science undergraduate course in Ship Studies, Marine Hydrodynamics and Ship Control. Previously he has lectured courses on Naval Architecture Dynamics, Ship Resistance and Propulsion and Fluid Mechanics. He has been awarded the medal of distinction of RINA on two occasions and was part of the team that was awarded the RINA/ Lloyd’s Register Safer Ship Award of 2006. Also the Donald Groen and PPE prizes were awarded from the Institution of Mechanical Engineers.

He has co-authored:
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